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Standards of performance for the control of emissions from ammonium sulfate manufacture plants are being proposed under the authority of Section 111 of the Clean Air Act. These standards would apply to new, modified, or reconstructed facilities at caprolactum by-product, synthetic and coke oven by-product ammonium sulfate manufacturing plants. This document contains background information, environmental and economic impact assessments, and the rationale for the standards, as proposed under 40 CFR Part 60, Subpart PP.

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Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

December 1979

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1.0 SUMMARY

1.1 PROPOSED STANDARDS

This Background Information Document (BID) supports proposed standards for particulate emissions from ammonium sulfate (AS) dryers within ammonium sulfate manufacturing plants. The proposed particulate matter emission limits apply to the three major segments of the AS industry: caprolactam by-product plants, synthetic plants, and coke oven by-product plants. Additional information and regulatory rationale may be found in the preamble and regulation for Subpart PP in the Federal Register.

The proposed emission standards under 40 CFR Part 60, Subpart PP would restrict particulate emissions from AS dryers to:

> 0.150 kilograms per megagram of AS production
> (0.30 pounds per ton); and
>
> 15 percent opacity.

Control of particulate emissions from AS manufacturing plants is achieved by installation of an emission control system to remove particulate matter from the exhaust gas stream. Venturi scrubbers have been adequately demonstrated to be the best technological system of continuous emission reduction for AS dryers. Fabric filters, though not considered the most attractive add-on control system, should also be able to achieve the level of control required by the standard.

1.2 ENVIRONMENTAL IMPACT

The proposed emission limit would reduce annual nationwide particulate emissions from AS dryers placed on line in AS manufacturing plants between 1980 and 1985 by about 539 Mg/year. This represents a reduction of about 80 percent in the emissions emitted under a typical State Implementation Plan (SIP) regulation. The proposed emission limits would not adversely affect water quality,

Table 1-1. MATRIX OF ENVIRONMENTAL AND ECONOMIC IMPACTS OF PROPOSED PARTICULATE EMISSION LIMITS

Impact Action	Air Pollution	Water Pollution	Solid Waste	Energy	Noise Pollution	Economic	Inflationary
Option I (No Standard)	0	0	0	0	0	0	0
Option II	$+3^{xx}$	0	0	-1^{xx}	0	-1^{xx}	0

Key:

+ Beneficial Impact
- Adverse Impact
0 No Impact
1 Negligible Impact
2 Small Impact

3 Moderate Impact
4 Large Impact
x Short-Term Impact
xx Long-Term Impact
xxx Irreversible Impact

solid waste disposal, energy conservation, or noise level. The environment impacts are summarized in Table 1-1.

1.3 ECONOMIC IMPACT

An economic impact assessment of the proposed emission limits has been prepared, as required under Section 317 of the Clean Air Act (as amended in 1977). The proposed limits would have negligible impact on compliance costs, inflation or recession, competition with respect to small business, consumer costs, and energy use. The standards would reduce profitability (as measured by rate of return on assets) by less than 1.0 percent.

The Agency's guideline for determining the necessity for developing an Inflationary Impact Statement is increased operating costs in the fifth year of operation of more than $100 million. The increase associated with the proposed limits is about $0.5 million per year.

The complete economic impact analysis appears in Chapter 8.0. A summary of the economic impacts of the proposed emission limits is also presented in Table 1-1.

2.0 INTRODUCTION

Standards of performance are proposed following a detailed investigation of air pollution control methods available to the affected industry and the impact of their costs on the industry. This document summarizes the information obtained from such a study. Its purpose is to explain in detail the background and basis of the proposed standards and to facilitate analysis of the proposed standards by interested persons, including those who may not be familiar with the many technical aspects of the industry. To obtain additional copies of this document or the Federal Register notice of proposed standards, write to EPA Library (MD-35), Research Triangle Park, North Carolina 27711. Specify Ammonium Sulfate Manufacturing Plants — Background Information for Proposed Particulate Emission Standards, report number EPA when ordering.

2.1 AUTHORITY FOR THE STANDARDS

Standards of performance for new stationary sources are established under Section 111 of the Clean Air Act (42 U.S.C. 7411), as amended, hereafter referred to as the Act. Section 111 directs the Administrator to establish standards of performance for any category of new stationary sources of air pollution which "... causes or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare."

The Act requires that standards of performance for stationary sources reflect, "... the degree of emission limitation achievable through the application of the best technological system of continuous emission reduction ... the Administrator determines has been adequately demonstrated." In addition, for stationary sources whose emissions result from fossil fuel combustion, the standard must also include a percentage reduction in emissions. The Act also provides that the cost of achieving the necessary emission reduction, the nonair quality health and environmental impacts and the energy requirements all be taken into account in establishing standards of performance. The standards apply only to stationary sources, the construction or modification of which commences after regulations are proposed by publication in the Federal Register.

The 1977 amendments to the Act altered or added numerous provisions which apply to the process of establishing standards of performance.

1. EPA is required to list the categories of major stationary sources which have not already been listed and regulated under standards of performance. Regulations must be promulgated for these new categories on the following schedule:

   25 percent of the listed categories by August 7, 1980

   75 percent of the listed categories by August 7, 1981

   100 percent of the listed categories by August 7, 1982

   A governor of a State may apply to the Administrator to add a category which is not on the list or to revise a standard of performance.

2. EPA is required to review the standards of performance every four years, and if appropriate, revise them.

3. EPA is authorized to promulgate a design, equipment, work practice, or operational standard when an emission standard is not feasible.

4. The term "standards of performance" is redefined and a new term "technological system of continuous emission reduction" is defined. The new definitions clarify that the control system must be continuous and may include a low-polluting or non-polluting process or operation.

5. The time between the proposal and promulgation of a standard under Section 111 of the Act is extended to six months.

Standards of performance, by themselves, do not guarantee protection of health or welfare because they are not designed to achieve any specific air quality levels. Rather, they are designed to reflect the degree of emission limitation achievable through application of the best adequately demonstrated technological system of continuous emission reduction, taking into consideration the cost of achieving such emission reduction, any nonair quality health and environmental impact and energy requirements.

Congress had several reasons for including these requirements. First, standards with a degree of uniformity are needed to avoid situations where some states may attract industries by relaxing standards relative to other states. Second, stringent standards enhance the potential for long-term growth. Third, stringent standards may help achieve long-term cost savings by avoiding the need for more expensive retrofitting when pollution ceilings may be reduced in the future. Fourth, certain types of standards for coal burning sources can adversely affect the coal market by driving up the price of low-sulfur coal or effectively excluding certain coals from the reserve base because their untreated pollution potentials are high. Congress does not intend that new source performance standards contribute to these problems. Fifth, the standard-setting process should create incentives for improved technology.

Promulgation of standards of performance does not prevent state or local agencies from adopting more stringent emission limitations for the same sources. States are free under Section 116 of the Act to establish even more stringent emission limits than those established under Section 111 or those necessary to attain or maintain the national ambient air quality standards (NAAQS) under Section 110. Thus, new sources may in some cases be subject to limitations more stringent than standards of performance under Section 111, and prospective owners and operators of new sources should be aware of this possibility in planning for such facilities.

A similar situation may arise when a major emitting facility is to be constructed in a geographic area which falls under the prevention of significant deterioration of air quality provisions of Part C of the Act. These provisions require, among other things, that major emitting facilities to be constructed in such areas are to be subject to best available control technology. The term "best available control technology" (BACT), as defined in the Act, means "... an emission limitation based on the maximum degree of reduction of each pollutant subject to regulation under this Act emitted from or which results from any major emitting facility, which the permitting authority, on a case-by-case basis, taking into account energy, environmental, and economic impacts and other costs, determines is achievable for such facility through application of production processes and available methods, systems, and techniques, including fuel cleaning or treatment or innovative fuel combustion techniques for control of each such pollutant. In no event shall application of 'best available control technology' result in emissions of any pollutants which will exceed the emissions allowed by any applicable standard established pursuant to Section 111 or 112 of this Act."

Although standards of performance are normally structured in terms of numerical emission limits where feasible, alternative approaches are sometimes necessary. In some cases physical measurement of emissions from a new source may be impractical or exorbitantly expensive. Section 111(h) provides that the Administrator may promulgate a design or equipment standard in those cases where it is not feasible to prescribe or enforce a standard of performance. For example, emissions of hydrocarbons from storage vessels for petroleum liquids are greatest during tank filling. The nature of the emissions, high concentrations for short periods during filling, and low concentrations for longer periods during storage, and the configuration of storage tanks make direct emission measurement impractical. Therefore, a more practical approach to standards of performance for storage vessels has been equipment specification.

In addition, Section 111(j) authorizes the Administrator to grant waivers of compliance to permit a source to use innovative continuous emission control technology. In order to grant the waiver, the Administrator must find: (1) a substantial likelihood that the technology will produce greater emission reductions than the standards require, or an equivalent reduction at lower economic, energy or environmental cost; (2) the proposed system has not been adequately demonstrated; (3) the technology will not cause or contribute to an unreasonable risk to public health, welfare or safety; (4) the governor of the state where the source is located consents; and that, (5) the waiver will not prevent the attainment or maintenance of any ambient standard. A waiver may have conditions attached to assure the source will not prevent attainment of any NAAQS. Any such condition will have the force of a performance standard. Finally, waivers have definite end dates and may be terminated earlier if the conditions are not met or if the system fails to perform as expected. In such a case, the source may be given up to three years to meet the standards, with a mandatory progress schedule.

2.2 SELECTION OF CATEGORIES OF STATIONARY SOURCES

Section 111 of the Act directs the Administrator to list categories of stationary sources which have not been listed before. The Administrator, "... shall include a category of sources in such list if in his judgment it causes, or contributes significantly to, air pollution which may reasonably be anticipated to endanger public health or welfare." Proposal and promulgation of standards of performance are to follow while adhering to the schedule referred to earlier.

Since passage of the Clean Air Amendments of 1970, considerable attention has been given to the development of a system for assigning priorities to various source categories. The approach specifies areas of interest by considering the broad strategy of the Agency for implementing the Clean Air Act. Often, these "areas" are actually pollutants which are emitted by stationary sources. Source categories which emit these pollutants were then evaluated and ranked by a process involving such factors as (1) the level of emission control (if any) already required by state regulations; (2) estimated levels of control that might be required from standards of performance for the source category; (3) projections of growth and replacement of existing facilities for the source category; and (4) the estimated incremental amount of air pollution that could be prevented, in a preselected future year, by standards of performance for the source category. Sources for which new source performance standards were promulgated or are under development during 1977 or earlier, were selected on these criteria.

The Act amendments of August 1977, establish specific criteria to be used in determing priorities for all source categories not yet listed by EPA. These are:

1. The quantity of air pollutant emissions which each such category will emit, or will be designed to emit;
2. The extent to which each such pollutant may reasonably be anticipated to endanger public health or welfare; and
3. The mobility and competitive nature of each such category of sources and the consequent need for nationally applicable new source standards of performance.

In some cases, it may not be feasible to immediately develop a standard for a source category with a high priority. This might happen when a program of research is needed to develop control techniques or because techniques for sampling and measuring emissions may require refinement. In the developing of standards, differences in the time required to complete the necessary investigation for different source categories must also be considered. For example, substantially more time may be necessary if numerous pollutants must be investigated from a single source category.

Further, even late in the development process the schedule for completion of a standard may change. For example, inability to obtain emission data from well-controlled sources in time to pursue the development process in a systematic fashion may force a change in scheduling. Nevertheless, priority ranking is, and will continue to be, used to establish the order in which projects are initiated and resources assigned.

After the source category has been chosen, determining the types of facilities within the source category to which the standard will apply must be decided. A source category may have several facilities that cause air pollution and emissions from some of these facilities may be insignificant or very expensive to control. Economic studies of the source category and of applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by a standard of performance, not all pollutants or facilities within that source category may be covered by the standards.

2.3 PROCEDURE FOR DEVELOPMENT OF STANDARDS OF PERFORMANCE

Standards of performance must (1) realistically reflect best demonstrated control practice; (2) adequately consider the cost, and the nonair quality health and environmental impacts and energy requirements of such control; (3) be applicable to existing sources that are modified or reconstructed as well as new installations; and (4) meet these conditions for all variations of operating conditions being considered anywhere in the country.

The objective of a program for development of standards is to identify the best technological system of continuous reduction which has been adequately demonstrated. The legislative history of Section 111 and various court decisions make clear that the Administrator's judgment of what is adequately demonstrated is not limited to systems that are in actual routine use. The search may include a technical assessment of control systems which have been adequately demonstrated but for which there is limited operational experience. In most cases, determination of the "... degree of emission reduction achievable ..." is based on results of tests of emissions from well controlled existing sources. At times, this has required the investigation and measurement of emissions from control systems found in other industrialized countries that have developed more effective systems of control than those available in the United States.

Since the best demonstrated systems of emission reduction may not be in widespread use, the data base upon which standards are developed may be somewhat limited. Test data on existing well-controlled sources are obvious starting points in developing emission limits for new sources. However, since the control of existing sources generally represents retrofit technology or was originally designed to meet an existing state or local regulation, new sources may be able to meet more stringent emission standards. Accordingly, other information must be considered before a judgment can be made as to the level at which the emission standard should be set.

A process for the development of a standard has evolved which takes into account the following considerations.

1. Emissions from existing well-controlled sources as measured.
2. Data on emissions from such sources are assessed with consideration of such factors as: (a) how representative the tested source is in regard to feedstock, operation,

size, age, etc.; (b) age and maintenance of the control equipment tested; (c) design uncertainties of control equipment being considered; and (d) the degree of uncertainty that new sources will be able to achieve similar levels of control.

3. Information from pilot and prototype installations, guarantees by vendors of control equipment, unconstructed but contracted projects, foreign technology, and published literature are also considered during the standard development process. This is especially important for sources where "emerging" technology appears to be a significant alternative.

4. Where possible, standards are developed which permit the use of more than one control technique or licensed process.

5. Where possible, standards are developed to encourage or permit the use of process modifications or new processes as a method of control rather than "add-on" systems of air pollution control.

6. In appropriate cases, standards are developed to permit the use of systems capable of controlling more than one pollutant. As an example, a scrubber can remove both gaseous and particulate emissions, but an electrostatic precipitator is specific to particulate matter.

7. Where appropriate, standards for visible emissions are developed in conjunction with concentration/mass emission standards. The opacity standard is established at a level that will require proper operation and maintenance of the emission control system installed to meet the concentration/mass standard on a day-to-day basis. In some cases, however, it is not possible to develop concentration/mass standards, such as with fugitive sources of emissions. In these cases, only opacity standards may be developed to limit emissions.

2.4 CONSIDERATION OF COSTS

Section 317 of the Act requires, among other things, an economic impact assessment with respect to any standard of performance established under Section 111 of the Act. The assessment is required to contain an analysis of:

1. The costs of compliance with the regulation and standard including the extent to which the cost of compliance varies depending on the effective date of the standard or regulation and the development of less expensive or more efficient methods of compliance;
2. The potential inflationary or recessionary effects of the standard or regulation;
3. The effects on competition of the standard or regulation with respect to small business;
4. The effects of the standard or regulation on consumer cost, and,
5. The effects of the standard or regulation on energy use.

Section 317 requires that the economic impact assessment be as extensive as practicable, taking into account the time and resources available to EPA.

The economic impact of a proposed standard upon an industry is usually addressed both in absolute terms and by comparison with the control costs that would be incurred as a result of compliance with typical existing state control regulations. An incremental approach is taken since both new and existing plants would be required to comply with state regulations in the absence of a Federal standard of performance. This approach requires a detailed analysis of the impact upon the industry resulting from the cost differential that exists between a standard of performance and the typical state standard.

The costs for control of air pollutants are not the only costs considered. Total environmental costs for control of water pollutants as well as air pollutants are analyzed wherever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potential adverse economic impacts can be made. It is also essential to know the capital requirements placed on plants in the absence of Federal standards of performance so that the additional capital requirements necessitated by these standards can be placed in the proper perspective. Finally, it is necessary to recognize any constraints on capital availability within an industry, as this factor also influences the ability of new plants to generate the capital required for installation of additional control equipment needed to meet the standards of performance.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decision-making process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards of performance for various industries, the Federal Courts of Appeals have held that environmental impact statements need not be prepared by the Agency for proposed actions under Section 111 of the Clean Air Act. Essentially, the Federal Courts of Appeals have determined that "... the best system of emission reduction, ... require(s) the Administrator to take into account counter-productive environmental effects of a proposed standard, as well as economic costs to the industry ..." On this basis, therefore, the Courts "... established a narrow exemption from NEPA for EPA determination under Section 111."

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act (ESECA) of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7(c)(1), "No action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969."

The Agency has concluded, however, that the preparation of environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, while not legally required to do so by Section 102(2)(C) of NEPA, environmental impact statements will be prepared for various regulatory actions, including standards of performance developed under Section 111 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the Agency to NEPA requirements.

To implement this policy, a separate section is included in this document which is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are identified and discussed.

2.6 IMPACT ON EXISTING SOURCES

Section 111 of the Act defines a new source as "... any stationary source, the construction or modification of which is commenced ..." after the proposed standards are published. An existing source becomes a new source if the source is modified or is reconstructed. Both modification and reconstruction are defined in amendments to the general provisions of Subpart A of 40 CFR Part 60 which were promulgated in the Federal Register on December 16, 1975 (40 FR 58416). Any physical or operational change to an existing facility which results in an increase in the emission rate of any pollutant for which a standard applies is considered a modification. Reconstruction, on the other hand, means the replacement of components of an existing facility to the extent that the fixed capital cost exceeds 50 percent of the cost of constructing a comparable entirely new source and that it be technically and economically feasible to meet the applicable standards. In such cases, reconstruction is equivalent to new construction.

Promulgation of a standard of performance requires states to establish standards of performance for existing sources in the same industry under Section 111(d) of the Act if the standard for new sources limits emissions of a designated pollutant (i.e. a pollutant for which air quality criteria have not been issued under Section 108 or which has not been listed as a hazardous pollutant under Section 112). If a state does not act, EPA must establish such standards. General provisions outlining procedures for control of existing sources under Section 111(d) were promulgated on November 17, 1975, as Subpart B of 40 CFR Part 60 (40 FR 53340).

2.7 REVISION OF STANDARDS OF PERFORMANCE

Congress was aware that the level of air pollution control achievable by any industry may improve with technological advances. Accordingly, Section 111 of the Act provides that the Administrator "... shall, at least every four years, review and, if appropriate, revise ..." the standards. Revisions are made to assure that the standards continue to reflect the best systems that become available in the future. Such revisions will not be retroactive but will apply to stationary sources constructed or modified after the proposal of the revised standards.

3. AMMONIUM SULFATE INDUSTRY

3.1 GENERAL

3.1.1 Overview

Ammonium sulfate (AS) has been an important nitrogen fertilizer source for many years. One of the reasons for AS's early rise to importance as a fertilizer material was that it developed as a by-product from such basic industries as steel and petroleum manufacturing. The amount of by-product generation has continued to dominate the AS production industry. In fact, by-product AS from the rapidly growing caprolactam segment of the synthetic fibers industry is now the single largest source of this material. The production of AS as a by-product from such large and basic industries ensures that it will continue to be an important source of U.S. nitrogen fertilizer tonnage.

Ammonium sulfate is one of the older forms of nitrogen fertilizer and is still used in significant quantities. However, since 1950 AS's share of the total nitrogen fertilizer market has declined as other nitrogen fertilizers (e.g., anhydrous ammonia, ammonium nitrate (AN), urea, and nitrogen solutions) have grown more rapidly. (This decline is also due to the increased demand for diammonium phosphate (DAP) as a raw material for a mixed fertilizer.)

Ammonium sulfate's percentage of the total nitrogen market will likely continue to decrease although total production may increase.[1] This possible increase in tonnage would be a result of additional by-product material from the steady growth in caprolactam production rather than from any new synthetic AS plants. The rapid increase in synthetic fiber demand (nylon-6), for which caprolactam is the production intermediate, means that approximately 1.8 to 4.0 Mg of AS will come on the market for every Mg of caprolactam produced.[2]

3.1.2 Uses for Ammonium Sulfate

In 1977, the total domestic AS production was about 2.1 million Mg. Over 95 percent of this total was consumed as fertilizer.[3] This proportion of total use is not expected to change appreciably. Based on 1975 data, approximately 32 percent of domestic production of AS was used as direct application fertilizer, 43 percent was used for NPK fertilizer mixtures, 20 percent was exported for fertilizer usage, and 5 percent was used domestically for miscellaneous purposes.*

3.1.3 Sources and Quantities of Ammonium Sulfate Production

Over 90 percent of ammonium sulfate is generated from three types of plants: synthetic, caprolactam by-product plants and coke oven by-product plants. Synthetic AS is produced by the direct combination of anhydrous ammonia and sulfuric acid. Caprolactam AS is produced as a by-product from two or three streams generated during caprolactam manufacture. The ammonia recovered from coke oven off-gas is reacted with sulfuric acid to produce coke oven AS. These three processes are reviewed in Section 3.2.

Table 3-1 provides an analysis of AS production in 1977 by number of production plants, plant capacity, actual production and percentage of capacity utilization. Currently, AS produced from three caprolactam AS plants is the largest source of AS production, representing about half of total supply.

3.1.4 Plant Sizes and Locations

Synthetic and caprolactam AS plants are fairly scattered around the U.S., while coke oven AS plants are concentrated heavily in the steel-producing states, particularly Ohio and Pennsylvania.

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*AS is used as an additive or raw material for the following products: livestock feeds, insulation, fermentation additive, photography, nylon dyes, ammonium alum, pharmaceuticals, hydrogen peroxide, printing ink and animal bone glue.[4]

Table 3-1. ANALYSIS OF 1977 AMMONIUM SULFATE PRODUCTION[5,6,7]

Source	Number of Plants	Capacity, 10^3 Mg (10^3 tons)	Production, 10^3 Mg (10^3 tons)	Percent of Total Production	Percent of Capacity Utilization[a]
Synthetic AS Production	10	790 (869)	456 (502)	21.2	58.0
Caprolactam By-Product AS Production	3	1593 (1752)	1102 (1212)	51.3	69.0
Coke Oven AS Production	40	529 (582)	427 (470)	19.9	80.7
Miscellaneous By-Product AS Production	7	288 (317)	164 (180)	7.6	57.0
TOTAL	60	3200 (3520)	2150 (2365)	100.0	

[a] The overall capacity utilization rate for 1977 was 68 percent.

The current average AS plant size for the three significant AS categories has been determined from 1977 production data and is tabulated in Table 3-2.

Table 3-2. AVERAGE AMMONIUM SULFATE PLANT SIZE

Source	Average plant size, Mg/yr (tons/yr)	Average plant size, Mg/hr (tons/hr)
Synthetic AS	79,000 (87,000)	13.3 (14)[a]
Caprolactam AS	531,000 (584,000)	60.6 (66)[b]
Coke Oven AS	13,200 (14,500)	1.8 (2.1)[a]

[a] Based on 24 hr/day, 300 day/yr operation.

[b] Based on 24 hr/day, 365 day/yr operation.

3.1.5 Future Trends in the Production of Ammonium Sulfate

Trends in the production and demand for AS over the next 4- to 5-year period are summarized in the following paragraphs.

3.1.5.1 Synthetic Ammonium Sulfate

Synthetic AS production is expected to remain fairly static with no new plants forecast.[8] Table 3-1 confirms the likelihood that no new synthetic AS production facilities will be added in the foreseeable future, since much of the presently available capacity is not being utilized.

3.1.5.2 AS from Coke Oven Gas

Coke oven AS capacity will not increase appreciably since most new coke oven batteries will be replacements, with some large new coke ovens recovering the by-product ammonia rather than producing AS.[9] The plants also have the process option to use phosphoric acid instead of sulfuric acid with the subsequent recovery of ammonium phosphate.

3.1.5.3 Caprolactam By-Product Ammonium Sulfate

Caprolactam demand has been projected to increase at a rate of 5 to 7 percent per year through the end of this decade.[10] However, the three present production plants, together with caprolactam imports, are expected to provide an adequate supply until at least 1980.

A continuation of this demand growth would indicate the likelihood of additional caprolactam and by-product AS capacity coming on-line from 1980 to 1990,[11,12] future AS dryers to be either installed as additions to existing plants or as part of an entirely new caprolactam plant.

3.1.5.4 Ammonium Sulfate from Miscellaneous Sources

Ammonium sulfate and sulfuric acid are by-products derived from the manufacture of methyl methacrylate (MMA) at one existing facility. However, no new plants of this type are expected to be built because new technology for future MMA plants eliminates the manufacture of AS.[13] The MMA plant with AS by-product may convert its plant to the new process in early 1980's thereby eliminating AS generation.[14]

AS is also produced as a by-product of nickel manufacture from ore concentrates at two U.S. plants. These plants indicate that another nickel refinery employing this process would not be installed until the mid- to late-1980s.[15]

Scrubbing of sulfuric acid plant tail gas using one of several available ammonia scrubbing processes does not appear to be a significant future source of this material since new sulfuric acid plants are all employing SO_2 control technology which does not generate by-product AS.[16]

3.2 PRODUCTION PROCESSES AND THEIR EMISSIONS

Ammonium Sulfate is produced from several types of plants (e.g., caprolactam AS plants, synthetic AS plants and steel industry coke oven AS plants). A generalized process flow diagram for the three major types of AS manufacturing plants is shown in Figure 3-1. The basic difference in the three production processes is the method of producing AS crystal from the various feedstocks. From the crystallization step onward, manufacturing operations are quite similar: they involve an AS crystal dewatering device and a drying device followed by a screening device.* In the following sections, the three AS manufacturing processes are discussed in detail.

3.2.1 Caprolactam By-Product Ammonium Sulfate

The typical process flow diagram developed for caprolactam by-product AS is shown in Figure 3-2. It is based on information obtained from inspections of the three U.S. caprolactam production plants and information derived from responses to EPA inquiries.** The material flow rates shown in Figure 3-2 are based on a dryer production rate of 23 Mg/hr of product (25 tons/hr). The majority of these plants contain more than one dryer production train and two or more crystallizers feeding a dryer.

The AS crystals are produced by continuously heating and circulating a 40 percent AS mother liquor through a draft tube-baffle crystallizer. The crystallizer typically operates in the temperature range of 77° to 82°C (170° to 180°F) and a pressure of about 660 mmHg (12.8 psia). Water vapor released from the crystallizers is condensed in one or more heat exchangers. A slurry of mother liquor and crystals, known as "magma," flows from the crystallizer to a settling tank. The magma may be combined with

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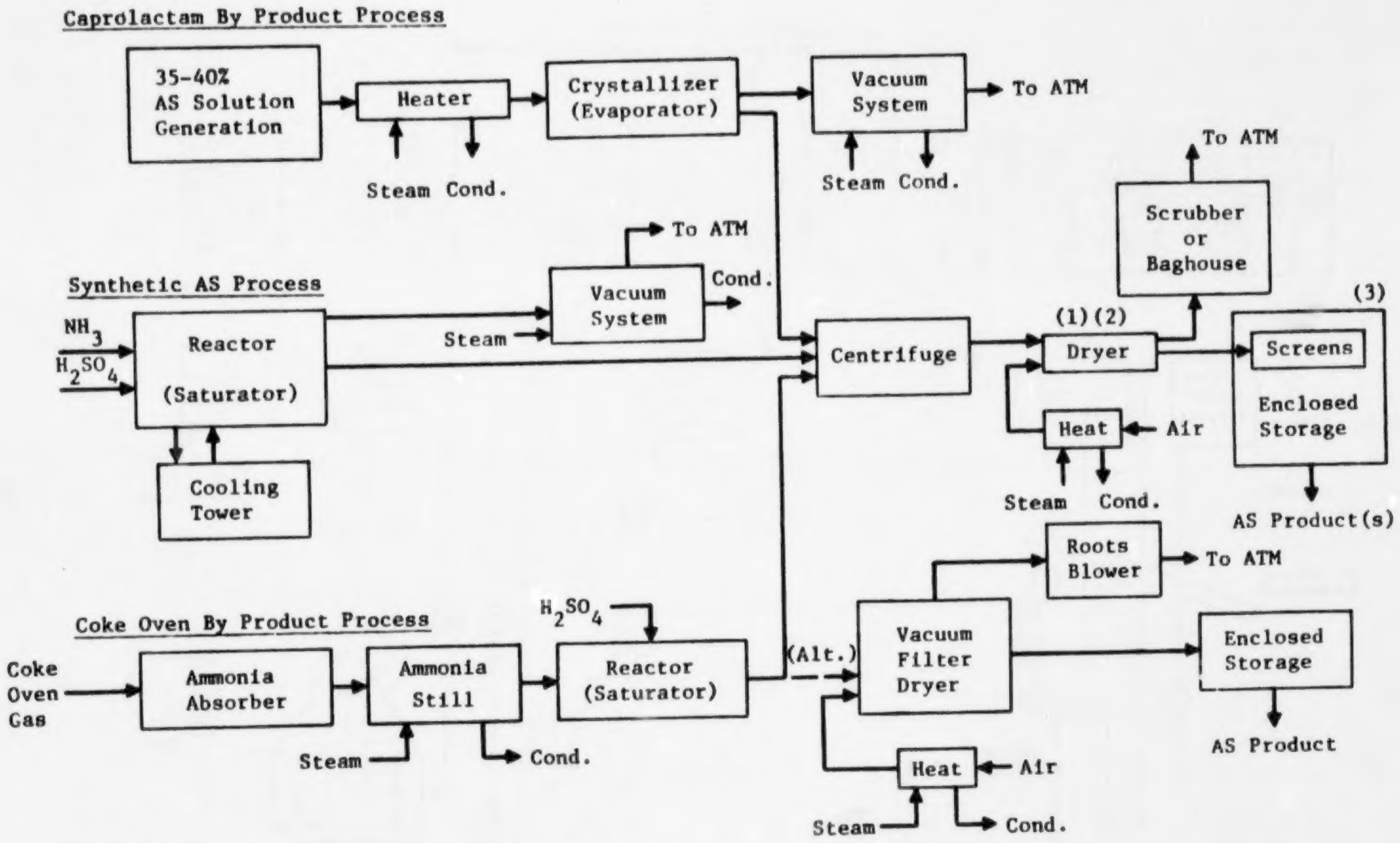
* Screening appears to be nonexistent in the coke oven by-product AS industry.

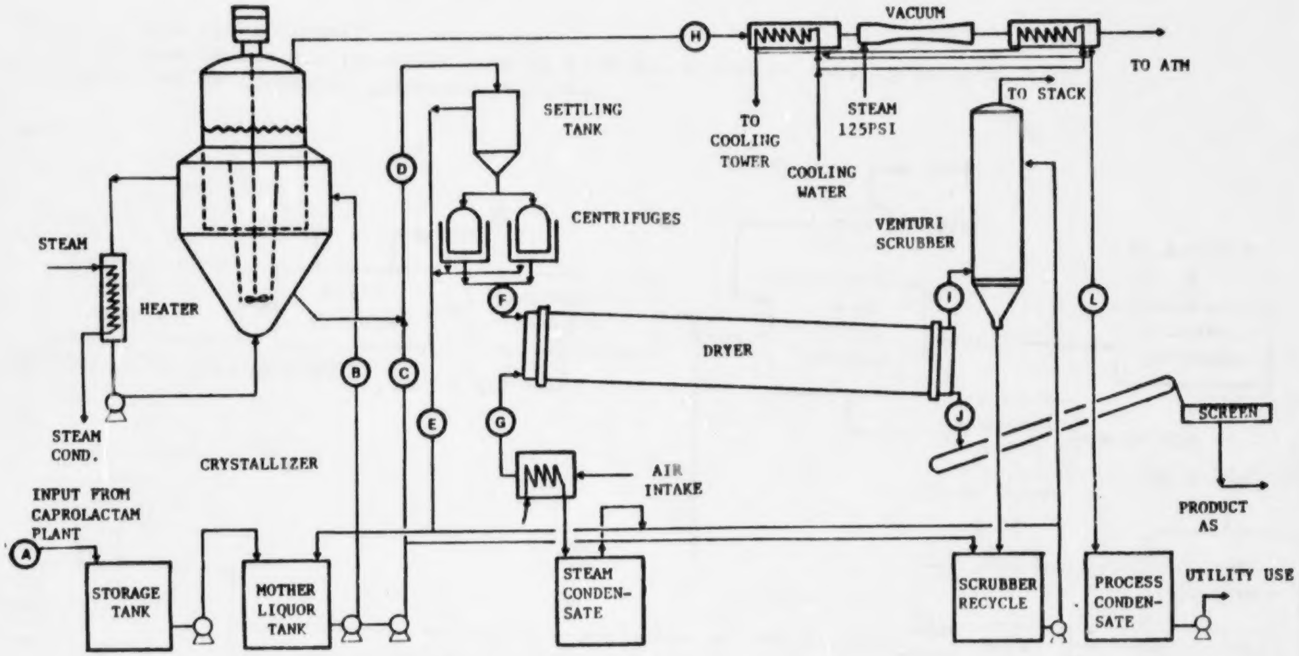
**Requests for information under the provisions of Section 114 of the Clean Air Act Amendments of 1977.



Notes:

1. Dryer may be rotary or fluidized bed type
2. Coke oven plants may integrate centrifuging and drying or centrifuge only
3. Coke oven plant product not screened

Figure 3-1. Flow diagram for ammonium sulfate processes.



Pounds/Hour

Line	A	B	C	D	E	F	G	H	I	J	K	L
Cryst AS	0	0	0	49,000	-	49,000	0	0	-	49,950	0	0
Liquid AS	50,000	102,000	30,500	83,300	82,300	1,000	0	0	-	0	4,100	0
Water	73,300	152,700	45,700	126,300	125,000	1,300	0	72,000	1,300	50	12,300	64,800
Total	123,300	254,700	76,200	258,600	207,300	51,300	0	72,000	1,300	50,000	16,400	64,800
Temp °F	AMB	AMB	200	150	115	120	300	-	175	175	150	-
Gas Flow	-	-	-	-	-	-	150,000	UK	150,000	-	-	-

Figure 3-2

AMMONIUM SULFATE PLANT CAPROLACTAM BY-PRODUCT PROCESS FLOW DIAGRAM

a mother liquor stream to facilitate transport to the settling tank. The settling tank is designed to reduce the liquid load on the centrifuges by decanting clear liquid overflow as the crystals settle to the bottom of the tank. The slurry feed to the crystallizer normally consists of 60 to 70 percent AS crystals.

The centrifuge performs a bulk separation between the AS crystals and mother liquor. In the centrifuge operation, the crystal throughput varies from 8 to 11 Mg/hr (9 to 12 tons/hr) per centrifuge for a two-centrifuge system. The number of centrifuges exceeds the number of crystallizers to provide spare centrifuge capacity in case lines become plugged with solid AS.

Inspections of the centrifuge installations at the three caprolactam plants determined the following with respect to AS emissions from these units:

1. At two-out-of-three plants, there were no visible AS particulate emissions from the centrifuge vents.
2. At the third plant, uncontrolled centrifuge AS emissions were estimated to be 0.01 kg/Mg (0.02 lb/tons).* All of the centrifuge vent lines were manifolded to a wet scrubber. According to the plant management, this was necessary because the centrifuges are located in an enclosed area, and they are subject to OSHA regulations pertaining to the area.

Dryers, which are the principal source of AS particulate emissions, can be either the fluidized bed or rotary drum type. All fluidized bed units found in the industry are heated continuously with steam-heated air. The rotary units are either direct-fired (oil or natural gas) or heated with steam-heated air. The fluidized bed dryers appear to be replacing rotary units in the newer installations. The following reasons for this trend were obtained from the literature and contact with vendors of this equipment:[17,18]

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*Data from Plant F response to EPA 114 letter.

1. In the fluidized bed unit AS fines tend to be swept out of the bed (in effect classifying the material) during the drying cycle, thus improving the particle size distribution and quality of the product. A granular AS product is claimed to be more marketable.

2. Space requirements for fluidized bed units are significantly less for the same throughput.

3. Capital and operating costs are less with fluidized bed units.

4. Heat and mass transfer rates are greater for fluidized bed units.

Gas flow rate, and heat and mass transfer rates are the important parameters for drying AS. According to a drying equipment vendor, a gas flow rate of 2200 scm/Mg of product (70,000 scf/ton) is considered representative for steam-heated air, while 600 scm/Mg of product (20,000 scf/ton) is typical for direct-fired dryers.[19] Based on data obtained from caprolactam plant visits, air flows for the AS dryers at caprolactam plants range from 560 scm/Mg (18,000 scf/ton) of product to 3200 scm/Mg (103,000 scf/ton) of product. The lower values represent direct-fired units and the higher values represent units using steam-heated air.[20]

EPA has recently conducted a series of AS emission tests on dryers at a number of AS production plants using EPA Method 5. Uncontrolled AS emission data are summarized in Table 3-3. Uncontrolled AS emissions for three rotary dryers ranged from 0.41 kg/Mg (0.82 lb/ton) to 77 kg/Mg (153 lb/ton) with an overall average of approximately 26 kg/Mg (52 lb/ton). Rotary drier data supplied by one AS manufacturer indicated an uncontrolled AS emission rate estimate of 20 kg/Mg (39 lb/ton), based on a material balance over the AS scrubbing equipment.[21] Data from an emissions test on a fluidized bed dryer at a caprolactam by-product AS plant indicated an average uncontrolled AS emission rate of 110 kg/Mg of product (221 lb/ton). The factors affecting uncontrolled emission rates from the dryer are discussed in Section 4.1.

Table 3-3. SUMMARY OF UNCONTROLLED AS EMISSION DATA - EPA EMISSION TESTS ON AS DRYERS*

Plant	Dryer type	Average uncontrolled AS emissions			
		gm/dscm	[gr(dscf)]	kg/Mg	(lb/ton)
A	Rotary Dryer	4.38	(1.93)	0.41	(0.82)
B	Fluidized Bed Dryer	39.0	(17.2)	110	(221)
C	Rotary Dryer	8.87	(3.91)	3.46	(6.92)
D	Rotary Dryer	98.3	(43.3)	77	(153)

*Detailed uncontrolled emission data for the individual plants is given in Appendix C, Tables C-1, C-4, C-6, and C-8.

At one caprolactam AS plant, the particulates and gas samples taken during EPA emission testing were analyzed for caprolactam; small concentrations of which are present in the dryer exhaust. Uncontrolled caprolactam particulate emissions averaged 0.011 g/dscm (3.3 ppm) equivalent to 1.12 Kg/hr (2.46 lb/hr). However, gas chromatograph measurements of the inlet gas phase samples, indicated a total caprolactam concentration of 0.272 g/dscm (57.8 ppm) equivalent to 19.6 Kg/hr (43.3 lb/hr). These rates are significantly higher than those reported by the company: 0.014 to 0.060 g/dscm (3 to 13 ppm). Based on the EPA test, most of the caprolactam emissions from the AS dryer (approximately 94 percent) are present in the vapor phase.

Caprolactam hydrocarbons (also referred to as volatile organic compounds) are carried over from the process streams which produce AS as a by-product. Caprolactam, $(CH_2)_5CONH$, has a melting point of 60°C and a boiling point of 140°C. This means that any caprolactam present in the AS dryer at the operating temperatures involved, about 85°C, is in the liquid phase. The caprolactam vapor present in the exit gas results from the vapor pressure at the temperature of the dryer. However, the majority of caprolactam is carried through the process. The liquid phase caprolactam in the dryer adheres to the AS crystals and passes through the drying and classifying process. This residual HC serves the useful purpose of preventing AS caking in storage. (Synthetic AS plants add a heavy hydrocarbon after drying in order to prevent caking.) The majority of caprolactam HC is removed from the system in this fashion.[22]

The AS crystalline product typically contains 2.0 to 2.5 percent water on entry to the dryer and 0.1 to 0.5 percent at the outlet. The product AS from the dryer is conveyed to an enclosure where it is screened, generally to coarse and fine products and the small mesh fines.* One coarse product contained 95 percent -6+18 mesh crystals and a standard fine crystal of -18 mesh with no fines recycle.* The screening operation is typically carried out within a building, and a screen enclosure may be used to minimize fugitive dust in the processing building.

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*The mixture of fines and oversize particles is sold as a so-called standard grade or the fines may be recycled to the process.

The parameters for a 23 Mg/hr (25 ton/hr) dryer in the typical AS production train are listed in Table 3-4.

The hot gases from the dryer are passed through an AS particulate collection device, typically a wet scrubber. In most cases, these devices are used both for product recovery and for pollution control. The air pollution control devices in use in this industry are discussed in Chapter 4.

3.2.2 Synthetic Ammonium Sulfate Production

Synthetic AS is produced from pure ammonia and concentrated sulfuric acid. The chemical reaction is essentially the neutralization of sulfuric acid with ammonia as indicated by the following chemical equation:

$$\underset{\text{Ammonia}}{2NH_3 \text{ (gas)}} + \underset{\text{Sulfuric Acid}}{H_2SO_4 \text{ (liquid)}} \rightarrow \underset{\text{Ammonium Sulfate}}{(NH_4)_2SO_4 \text{ (solid)}} + \text{HEAT}$$

This reaction is highly exothermic, liberating approximately 67,710 cal/g mole or 120,000 Btu/lb mole of product. The raw materials are reacted in neutralizer/crystallizer units designed with means of controlled heat removal. Heat removal is achieved by controlled water addition and evaporation under either vacuum (subatmospheric) or atmospheric pressure conditions. By regulating water evaporation and slurry recirculation rates in the neutralizer/crystallizer, an appropriate amount of cooling/evaporation and percent of solids in the slurry is achieved for optimum crystal size formation. Precipitated crystals are separated from the mother liquor (dewatered) usually by centrifuges. Following dewatering the crystals are dried and screened to product specifications.

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*No. 6 mesh has a particle opening of 0.132 in. and No. 18 a particle opening of 0.039 in.

Table 3-4. TYPICAL PARAMETERS FOR A CAPROLACTAM BY-PRODUCT AMMONIUM SULFATE PLANT DRYER

Parameter	Type/Value
Dryer	Rotary or Fluidized Bed
Product flow through dryer, Mg/hr (tons/hr)	23 (25)
Air flow through dryer, scm/min (scfm)	825 (29,200)
acm/min (acfm) @85°C (185°F)	1000 (35,500)
Air flow per ton of product, scm/Mg(scf/ton)	2490 (80,000)
Air temperature	
Inlet to dryer °C (°F)	149 (300)
Outlet of dryer °C (°F) (Inlet to scrubber)	85 (185)
AS Uncontrolled AS emission from dryer	
kg/Mg of product (lb/ton)	
Rotary dryer	26 (52)
FB dryer	111 (221)
AS Product temp., and water content, wt. percent	
Dryer inlet 66° C (150° F)	2.0-2.5
Dryer outlet 80° C (175° F)	0.1-0.5
Water evaporated per ton of product $\frac{kg}{Mg}\left(\frac{lb}{ton}\right)$	24-25 (48-50)
Steam input to dryer kg cal/hr (Btu/hr)	3,024,000 (12,000,000)
Sat 125 psig at 177° C (350° F)	

The typical plant configuration for the synthetic AS plant is shown in Figure 3-3. It is based on the results of four plant trips and information derived from responses to EPA inquiries.* Figure 3-3 includes a schematic of a typical synthetic AS plant. Material flow rates shown in Figure 3-3 are based on a dryer production rate of 13.7 Mg/hr (15 tons/hr).

Anhydrous ammonia and concentrated sulfuric acid are combined in a crystallizer similar to the draft tube baffle type used in caprolactam by-product AS plants. However, a cooling section or external heat exchanger is used to dissipate much of the heat generated in the reaction. The mother liquor is injected at the point of reaction to improve the cooling.

The crystallizer shown has an "elutriation leg" at the magma discharge. Mother liquor flowing in this leg blows back or "elutriates" the fine particles of AS into the main chamber but allows the larger particles to pass to the discharge point. This action tends to produce a uniform crystal size distribution.

The AS crystal slurry leaves the crystallizer at a temperature of about 95°C, and is pumped to one or more centrifuges. The centrifuges remove most of the mother liquor which is then returned to the reactor/crystallizer. No visible emissions were observed from centrifuges at the four synthetic AS plants visited.

The AS crystals, containing typically 1 to 2 percent moisture, are then fed to the AS dryer. One plant operator indicates that during hot days, these crystals can become so dry following centrifugation that the dryer can be operated at times without heat.[23] As in the caprolactam process, the AS dryer is the only significant emission source in the process. Only rotary dryers are known to be used in synthetic AS production plants. The dryer gas flows

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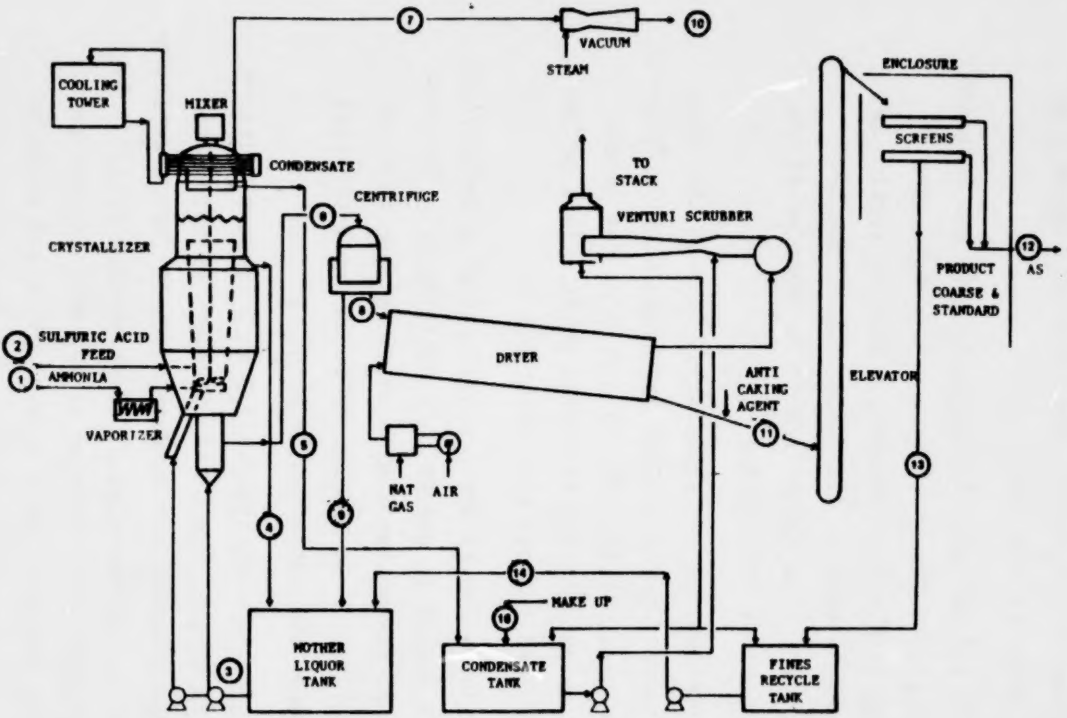
*Requests for information under the provisions of Section 114 of the Clean Air Act Amendments of 1977.



Mass Bal: Pounds/Hour

Line	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
NH_3	7,730															
H_2SO_4		22,270	9,800	9,000		800			800							
H_2O	80	450	550,000	493,000	14,000	40,000	3,600	700	39,300	630	70	63	7	17,700	5,400	3,700
Liq AS			570,000	529,200		37,200			37,200					3,650	54	
Cryst AS			11,000	11,000		33,600		33,600			33,600	30,000	3,600			
Total	7,810	22,720	1,140,000	1,042,200	14,000	111,600	3,600	34,300	77,300	630	33,670	30,063	3,607	21,350	5,454	3,700

Figure 3-3
PROCESS FLOW DIAGRAM SYNTHETIC AMMONIUM SULFATE PLANT

and the flow rate per ton of product for the four plants visited are shown in Table 3-5. The parameters for the 13.7 Mg/hr (15 ton/hr) dryer in the typical synthetic AS plant are shown in Table 3-6.

Based on rotary dryer design information supplied by a vendor of these units (Table 3-7), the gas flow rate per ton for the direct-fired dryers appears to be within the range of field measurements. Uncontrolled AS emissions from the rotary dryers are summarized in Table 3-3, and average 26 kg/Mg (52 lb/ton) of product, based on recent EPA emission test measurements (see Section 4.5).

The product output of the dryer is passed on to screens where a coarse and standard product may be separated with possible recycle of fines. Screens are normally located inside a storage building. Fugitive dust from the screening operations are minimal. The AS product conveyors and elevators are enclosed and may be located in buildings.

The synthetic plants add a small quantity (approximately 0.05 percent)[26] of a heavy hydrocarbon such as "Armoflow" to the product as it emerges from the dryer to control caking. The hot AS emission-laden gases from the dryer are sent through a particulate collection device for air pollution control and then vented to the atmosphere. Control devices in use in this industry are discussed in Chapter 4.

3.2.3 Ammonium Sulfate from Coke Oven Gas

In the process of carbonizing coal to coke such as in the steel industry, coal volatiles including ammonia, ammonium hydroxide and ammonium chloride are liberated. Many of the bituminous coals used in coke production contain 1 to 2 percent nitrogen, and approximately 15 to 20 percent of this quantity can be recovered as ammonia. Ammonia formation is normally considered to occur at coking temperatures of approximately 1000°C (1832°F) such as those utilized in steel industry coking operations.[27] The production of ammonium sulfate

Table 3-5. GAS FLOW RATES AND CAPACITIES (SYNTHETIC AMMONIUM SULFATE PLANTS)[24]

	Gas flow, scm/m (scfm)	AS capacity, Mg/hr (tons/hr)	Gas flow, scm/Mg (scf/ton)	Method of dryer heating	Type of dryer
Plant G	240 (8,560)	19 (21)	770 (24,500)	Steam Heated Air	Rotary
Plant A	60 (2,030)	16 (18)	210 (6,800)	Direct Fired	Rotary
Plant D	85 (3,000)	8.4 (9.2)	610 (19,600)	Direct Fired	Rotary
Plant C	90 (3,180)	8.5 (9.3)	640 (20,500)	Direct Fired	Rotary
Plant C	110 (3,950)	16.5 (18.1)	410 (13,000)	Direct Fired	Rotary

Table 3-6. TYPICAL PARAMETERS FOR A SYNTHETIC AMMONIUM SULFATE PLANT DRYER

Parameter	Type/Value
Dryer type	Rotary, direct-fired
Product flow through dryer $\frac{Mg}{hr}\left(\frac{tons}{hr}\right)$	13.7 (15.0)
Air flow through dryer scm/min (scfm)	135 (4750)
acm/min (acfm) @ 93° C (200° F)	170 (5920)
Air flow per ton of products scm/Mg $\left(\frac{scf}{ton}\right)$	620 (20,000)
Air temperature	
Inlet to dryer °C (°F)	232 (450)
Outlet to dryer °C (°F)	93 (200)
AS uncontrolled emission from dryer, kg/Mg (lb/ton) of product	26 (52)
Product temp and water content, wt. percent	
Dryer inlet 88° C (190° F)	2.0-2.5
Dryer outlet 93° C (200° F)	0.1-0.5
Water evaporated per ton of product $\frac{kg}{Mg}\left(\frac{lb}{ton}\right)$	24-25 (48-50)
Natural gas input to dryer kg cal/hr (Btu/hr)	504,000 (2,000,000)

Table 3-7. DESIGN DATA ON ROTARY DRYERS USED FOR AMMONIUM SULFATE DRYING[25]

Number	Dryer Size Diam x Length	Dryer Cross-Section m^2 (ft^2)	AS Particle Size	AS Throughput Mg/hr (tons/hr)	Type of Dryer Heating	Inlet Gas Temp. °C (°F)	Outlet Gas Temp. °C (°F)	Log Mean Temp. (LMT) °C (°F)	Gas Velocity at LMT m/min (ft/min)	Gas Flow		
										am^3/min (acfm)	sm^3/min (scfm)	sm^3/ton (scf/ton)
1	1.8m x 10.7m (6ft x 35ft)	2.6 (28.3)	95% -10 mesh +60 mesh	9.1 (10)	Steam Heated Air	176 (350)	66 (150)	138 (281)	100 (330)	264 (9,330)	225 (7,950)	1,488 (47,700)
2	2.6m x 13.7m (8-1/2ft x 45ft)	5.2 (56.7)	100% -20 mesh +40 mesh	18.6 (20.5)	Steam Heated Air	149 (300)	66 (150)	104 (219)	97.5 (320)	513 (18,140)	438 (15,460)	1,411 (45,248)
3	1.8m x 12.2m (6ft x 40 ft)	2.6 (28.3)	3% +8 mesh 85% -8 mesh	14.7 (16.2)	Direct Fired	199 (390)	90 (195)	140 (285)	97.5 (320)	256 (9,060)	203 (7,190)	830 (26,683)

from coke oven gas is the most common approach taken for the recovery of ammonia from the coking of coal. The AS production from recovered ammonia is accomplished by one of three different methods: direct, indirect and semidirect processes, according to the method of contacting the ammonia and sulfuric acid.[28]

The direct process treats the mixture of volatile off-gases from coke production by first cooling them to remove the maximum possible quantity of tar. Following tar removal the gases are passed through a saturator--either a bubbler or spray type--where they are washed with sulfuric acid. The AS crystals form in the liquor and are recirculated in the saturator until the desired crystal size is formed. After the desired crystal size is realized, this material is separated from the liquor by centrifugation, washed, dried and conveyed to storage.

The indirect process was developed primarily to improve AS crystal purity by further removal of such contaminates as tar, pyridine and other organic compounds. In this method the volatile off-gases are first cooled by recirculated wash liquor and scrubbing water. These liquors are then combined and treated with steam in a stripping column to release relatively high purity "free" ammonia present in the forms of such easily disassociated salts as ammonium carbonate and ammonium sulfide. The partially stripped liquor is then treated with lime solution to decompose such "fixed" salts as ammonium chloride. This treated liquor then passes to a second stripping column where essentially all the remaining ammonia is freed from the liquor. The stripped ammonia is recovered as a crude ammonia solution which in turn is redistilled or converted directly to AS in a saturator/crystallizer.

The semidirect process was developed from both the above techniques. The volatile off-gases are cooled and washed to remove the majority of the tar and yield an aqueous condensate containing a high percentage of the ammonia present in the gas. Ammonia is then released from this aqueous condensate in a small still. The evolved ammonia is then recombined with the main gas stream and the whole stream reheated to approximately 21°C (70°F). This reheated gas stream is then scrubbed with 5 to 6 percent sulfuric acid and a near-saturation 60 to 70 percent ammonium sulfate solution. Spray-absorbers or saturators are used for this operation. Ammonium sulfate crystals are formed and removed as product similar to the previously described procedure. The semidirect process yields an essentially pure AS and high ammonia recovery.

In the schematic process flow diagram (Figure 3-4), the first step is the concentration of ammonia in the coke oven off-gas stream. The AS is then produced by continuously reacting the concentrated ammonia stream with sulfuric acid in a simple "saturator." As the AS product concentrations increase, crystals drop to the bottom of the reactor and are pumped as a slurry to storage. This type of process is reported to be the most widely used in the industry.[29] Alternatively, the detarred coke oven gas stream, which contains a low percentage of ammonia, is contacted with dilute sulfuric acid in a stream of mother liquor in an absorber to produce a dilute AS solution which is then concentrated by evaporation. From this point on, the plant may be operated in batch-wise fashion with a frequency sufficient to handle the AS accumulation in storage, or the AS slurry is processed on a continuous basis. The slurry is pumped to a settling tank (not shown in Figure 3-4) where it is settled to a concentration of about 80 percent solids.

As shown in Figure 3-4 the AS is then dried by various procedures. In one of the plants visited, the AS is then pumped to a rotary vacuum filter which combines the operations of filtration and drying.[30] In other plants, the two operations may be carried out in separate units. Alternatively, the dewatering-drying operation is carried out using a combination centrifuge-dryer or in a centrifuge followed by a rotary dryer.[31] Of the 12 coke plants

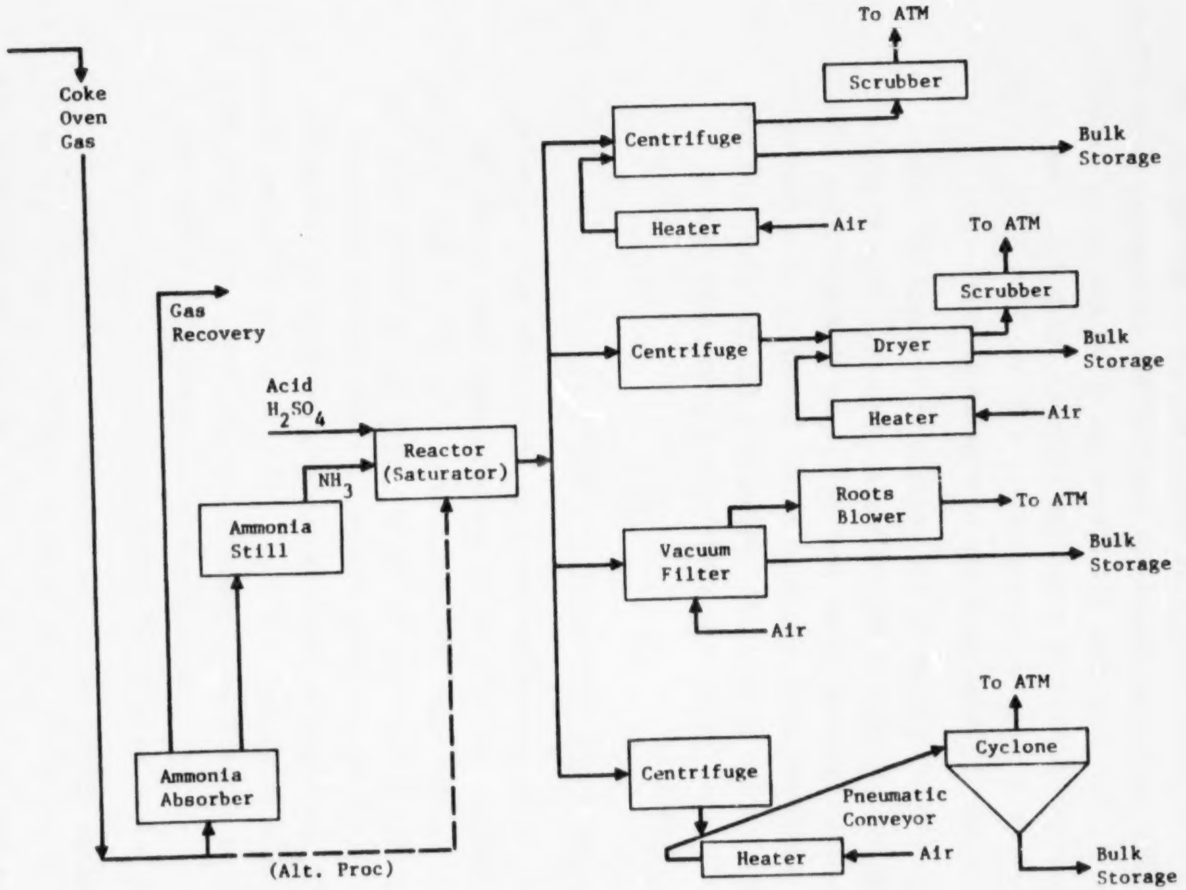


Figure 3-4. Process flow diagram for coke oven ammonium sulfate plants showing alternate process for product drying.

recovering by-product ammonia as AS which were surveyed, approximately half use rotary vacuum filters as dewatering-drying devices and the balance employ centrifuge-dryers or combinations of separate centrifuges and dryers.[32] Air flow data for plants employing the rotary vacuum filter dryer and centrifuge dryer are shown in Table 3-8. The results show an average of approximately 1100 scm/Mg (35,000 scf/ton) if the plant No. 2 system data are discounted as oversized.

Mother liquor removed in the process is returned to storage or recycled in the case of the continuous process. The AS product contains a wide range of sizes from coarse to fine particles. It is fed by conveyors to a warehouse pile. Normally, no screening is performed on the product AS. Parameters for the dryer are shown in Table 3-9 based on an estimated typical production rate of 2.7 Mg/hr (3 tons/hr).

3.3 EMISSIONS UNDER EXISTING REGULATIONS

Allowable AS particulate emission rates under most existing state regulations are related to process weight rate which, in most cases, is the dryer throughput rate. For plants that recycle screened product, the dryer throughput rate may be higher than the final production rate. Other states have regulations limiting particulate emissions from process sources based on concentrations and/or visible emissions. In Texas, AS particulate emissions are determined as a function of process vent gas flow. Figure 3-5 is a display of allowable partiuclate emission rates as a function of process weight rate for 39 states.

A process weight regulation defined by E (pounds/hour of emissions) = $4.1\ P^{0.67}$ (tons/hour of dryer throughput) is used by the greatest number of states--21 out of 50-- for process weight rates less than 27 Mg/hr. For this reason, this regulation is selected as the baseline emission level which is used to evaluate the environmental and economic impacts associated with various emission

Table 3-8. ESTIMATED AIR FLOWS FOR COKE OVEN PLANT AMMONIUM SULFATE DRYERS[a]

Plant No.	System	Production rate, Mg/hr (tons/hr)	Air flow, scm/m (scfm)	Air flow/ton, scm/Mg (scf/ton)	Reference Number
1	Combination centrifuge and dryer	5.5 (6.0)	115 (4000)	1250 (40,000)	33
2	Vacuum filter-dryer	3.4 (3.7)	142 (5000)	2535 (81,000)	34
3	Rotary	2.1 (2.3)	29.5 (1040)	845 (27,000)	35
4	Vacuum filter-dryer	4.6 (5.0)	79.3 (2800)	1060 (33,800)	36

[a] Estimates based on reported fan or blower sizes.

Table 3-9. ESTIMATED PARAMETERS FOR A COKE OVEN AMMONIUM SULFATE DRYER

Parameter	Type/Value
Dryer	Rotary vac. filter-dryer, centrifuge-dryer or rotary dryer
Product flow through dryer $\frac{Mg}{hr} \left(\frac{tons}{hr}\right)$	2.7 (3.0)
Air mass flow assumed per ton product $\frac{scm}{Mg} \left(\frac{scf}{ton}\right)$	1095 (35,000)
Air flow through dryer scm/min (scfm)	50 (3,500)
Air temperature	
Inlet to dryer °C (°F)	149 (300)
Outlet to dryer °C (°F)	80 (175)
AS uncontrolled emission from the dryer, kg/Mg of product (lb/ton)	10.0 (20.0)[a]
Product temperature and water content percent	
Dryer inlet - 49°C (120°F)	2.5
Dryer outlet - 66°C (150°F)	0.5
Water evaporated, kg/Mg (lb/ton)	20 (40)
Steam heat input to dryer kg cal/hr (Btu/hr)	163,800 (650,000)

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[a] Estimated based on 1 percent of AS product appearing as uncontrolled dryer emissions.

control alternatives.* As shown in Figure 3-5, this regulation is also the least stringent regulation for process weight rates less than 27 Mg/hr. The weighted average allowable emission rate, considering all state regulations, is estimated to be only 10 to 20 percent less than the selected baseline emission level.

Table 3-10 compares the allowable mass emissions under existing state regulations with mass emissions based on a 0.044 g/dscm (0.02 gr/dscf) controlled grain loading, for a process weight range of 2.3 to 45.4 Mg/hr (2.5 to 50 tons/hr).

For a typical large AS production train of 23.7 Mg/hr (25 tons/hr), allowable particulate emissions from the AS dryer show an order of magnitude spread, ranging from a low of 2.6 kg/hr (5.7 lb/hr)** for two states (having the most stringent regulations) to a high of 16 kg/hr (35 lb/hr) for 25 states. For a typical medium sized AS production train of 13.7 Mg/hr (15 tons/hr), allowable particulate emissions from the AS dryer also show an order of magnitude spread, ranging from a low of 1.6 kg/hr (3.4 lb/hr)** for two states to a high of 11.8 kg/hr (26 lb/hr) for 21 states.

Based on inspections of all the caprolactam AS plants and four of the eight synthetic AS plants, all of these facilities appear to be meeting existing state regulations on emissions from the AS dryer. Observations at the two coke oven AS plants visisted indicated that the dryers at these facilities were meeting state emission regulations.

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*Baseline emission level is that level which can be achieved by state and local regulations in the absence of additional standards of performance.

**The high emission values presented are based on equations relating process emissions to production rate. The low emission values are based on a fixed allowable grain loading of 0.044 g/dscm (0.02 gr/dscf) and an assumed vent gas flow of 2490 scm/Mg of product 80,000 scf/ton).

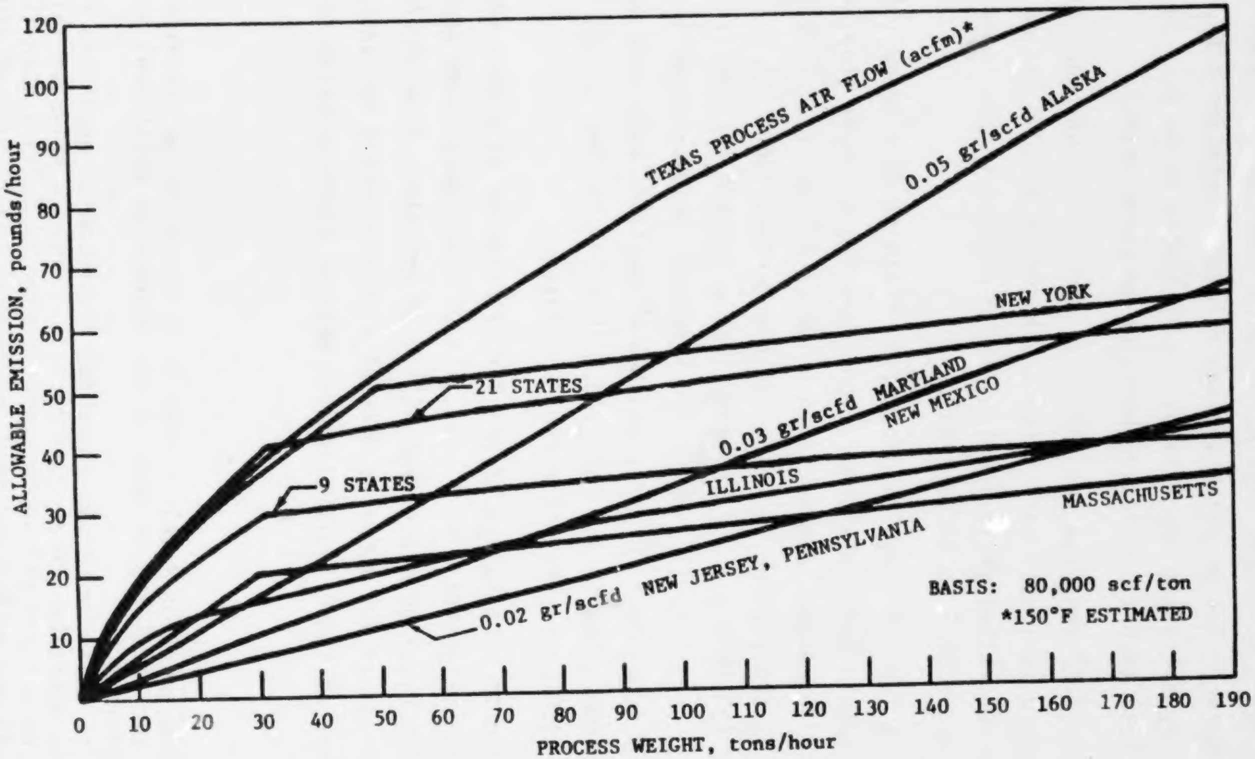

Figure 3-5. State Regulation Limitations on Particulate Emission From New Processes

Table 3-10. COMPARISON OF ALLOWABLE EMISSIONS UNDER GENERAL STATE PROCESS WEIGHT REGULATIONS

Process Weight Rate (Dryer Throughput)		Allowable Emissions			
		Control to 0.02 gr/dscf[1]		Typical[2]	
Mg/hr	(tons/hr)	kg/hr	(lbs/hr)	kg/hr	(lbs/hr)
2.3	(2.5)	0.3	(0.6)	3.5	(7.8)
4.5	(5.0)	0.7	(1.5)	5.9	(13.0)
9.1	(10.0)	1.0	(2.3)	8.7	(19.2)
13.6	(15.0)	1.5	(3.4)	11.4	(25.2)
18.1	(20.0)	2.1	(4.6)	13.8	(30.5)
22.7	(25.0)	2.6	(5.7)	16.1	(35.4)
27.2	(30.0)	3.1	(6.9)	18.1	(40.0)
36.3	(40.0)	4.1	(9.1)	19.3	(42.5)
45.4	(50.0)	5.2	(11.4)	20.2	(44.6)

[1] Basis: 2490 dscm/Mg (80,000 dscf/ton)

[2] E lbs/hr = 4.1 (P, tons/hr.)$^{0.67}$ at P less than 30 tons/hr

E lbs/hr = 55 (P, tons/hr)$^{0.11}$ - 40 at P greater than 30 tons/hr

3.4 REFERENCES

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2. Chemical Economics Handbook. Stanford Research Institute. Menlo Park, California. December 1976. p. 756.6002E.

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4. EMISSION CONTROL TECHNIQUES

This chapter discusses the control technology applicable to dryers at AS manufacturing plants. As discussed in Chapter 3, the dryer is the only significant source of particulate emissions. At caprolactam AS plants, the dryer may also be a source of caprolactam emissions. Fugitive particulate emissions from equipment for screening and materials handling are not significant; therefore, control technology for these sources is not discussed.

4.1 FACTORS AFFECTING EMISSION CONTROL TECHNIQUES

The type of emission control equipment applied to the AS dryer depends on a number of factors, the most important of which are the:

1. Chemical and physical properties of AS,
2. Particle size distribution of the emissions,
3. Amount of uncontrolled emissions in the dryer vent gas.

4.1.1 Chemical and Physical Properties of Ammonium Sulfate

At the operating temperatures of the dryers (in the 100° to 150°C range), AS emissions occur as a solid particulate. Only above a temperature of 235°C will it decompose. The solid is an inorganic salt, but it can become contaminated with organic impurities such as caprolactam at caprolactam by-product AS plants and tars at coke oven by-product AS plants. Because the salt exhibits a moderately high solubility in water, wet scrubbing is commonly used. Figure 4-1 shows the relationship of solubility and AS solution temperature. At some plants the scrubber solution concentration is maintained near the saturation limit (approximately 45 percent AS at plant operating temperatures). The AS scrubber solution is strongly acidic (pH of 2 to 4), necessitating consideration to materials of construction. The AS is moderately hygroscopic and has a tendency to agglomerate into hard lumps on absorption of moisture while in storage. Organic anti-caking agents, required for the synthetic AS product, are added to

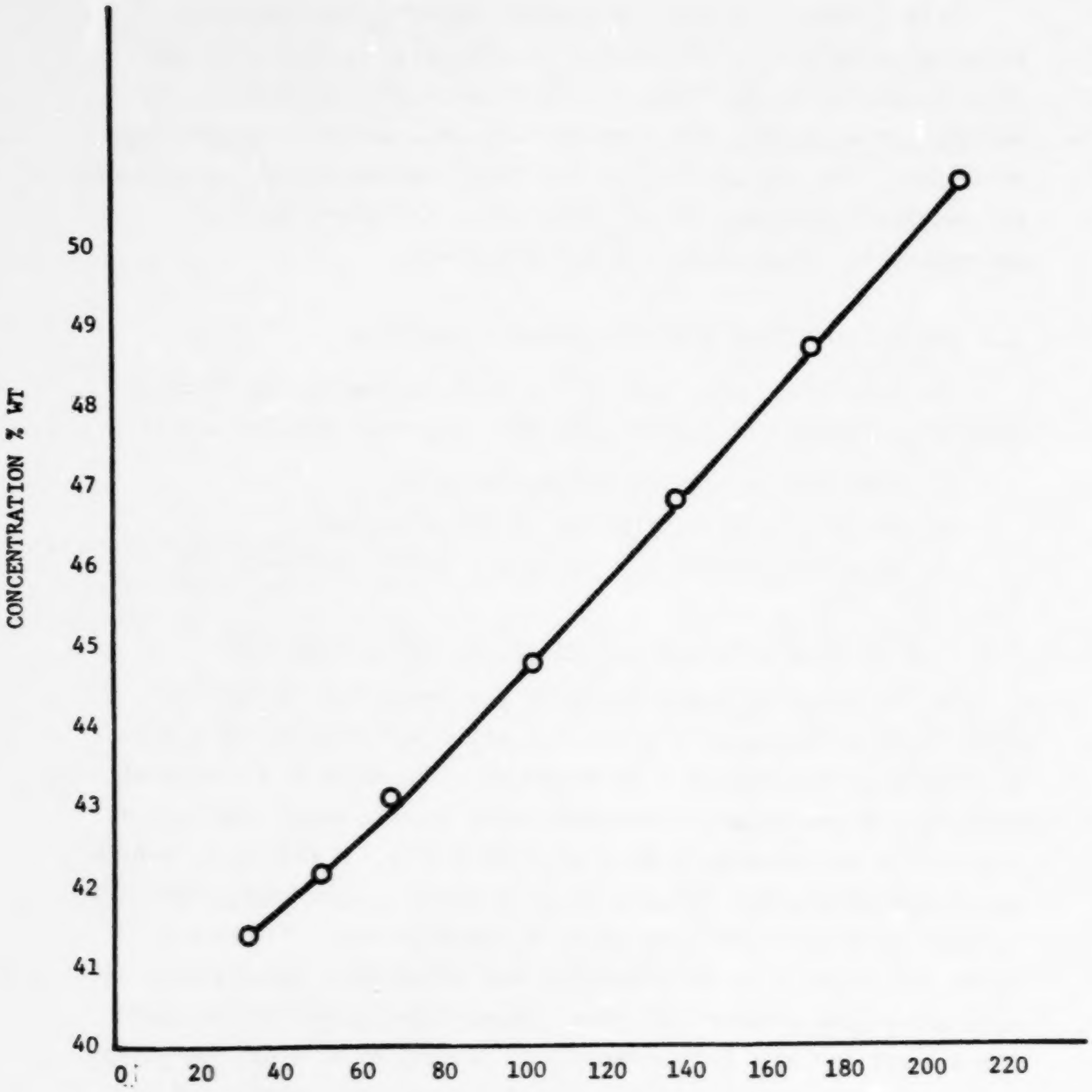

FIGURE 4-1

SOLUBILITY OF AMMONIUM SULFATE IN WATER VS TEMPERATURE the dryer product; therefore, they do not pass through the control device.

4.1.2 Particle Size Distribution of Uncontrolled AS Emissions

Test data have been obtained on the particle size distribution of uncontrolled AS particulate emissions from a number of different dryers and are presented in Figure 4-2*. These results indicate that from 93 to 99+ percent by weight of the particles are greater than 1 micron. It should be noted that the particle size distribution from the one fluidized bed dryer tested (Plant B) indicated a significantly larger percentage of particles greater than 1 micron (over 99.9+ percent) as compared with the rotary dryer results--the latter ranging from 93 to 99.9 percent greater than 1 micron.

4.1.3 Uncontrolled AS Emission Rates

The mechanism responsible for entrainment of particulate matter by dryer gases is aerodynamic drag. The drag force depends upon several factors such as gas and particulate velocities and the physical properties of the gas and solid.

The gas velocity and particle size distribution of the dryer feed are the primary factors influencing uncontrolled dryer emission rates. The type of dryer or type of mechanism for moving the solids through the dryer (rotating flights or fluidizing air) also affects the quantity of particulate which becomes airborne. Figure 4-3 shows the relationships between gas flow and uncontrolled AS dryer emission rates for the facilities tested by EPA.

The uncontrolled AS emission rate of 111 kg/Mg (212 lb/ton) measured from one fluidized bed dryer, is higher than the rates measured from three rotary dryers ranging from 0.4 kg/Mg to 77 kg/Mg (0.8 lb/ton to 153 lb/ton). Fluidized bed dryers would, therefore,

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*Detailed tabulations of particle-size distribution test results are presented in Appendix C, Tables C-12 through C-15.

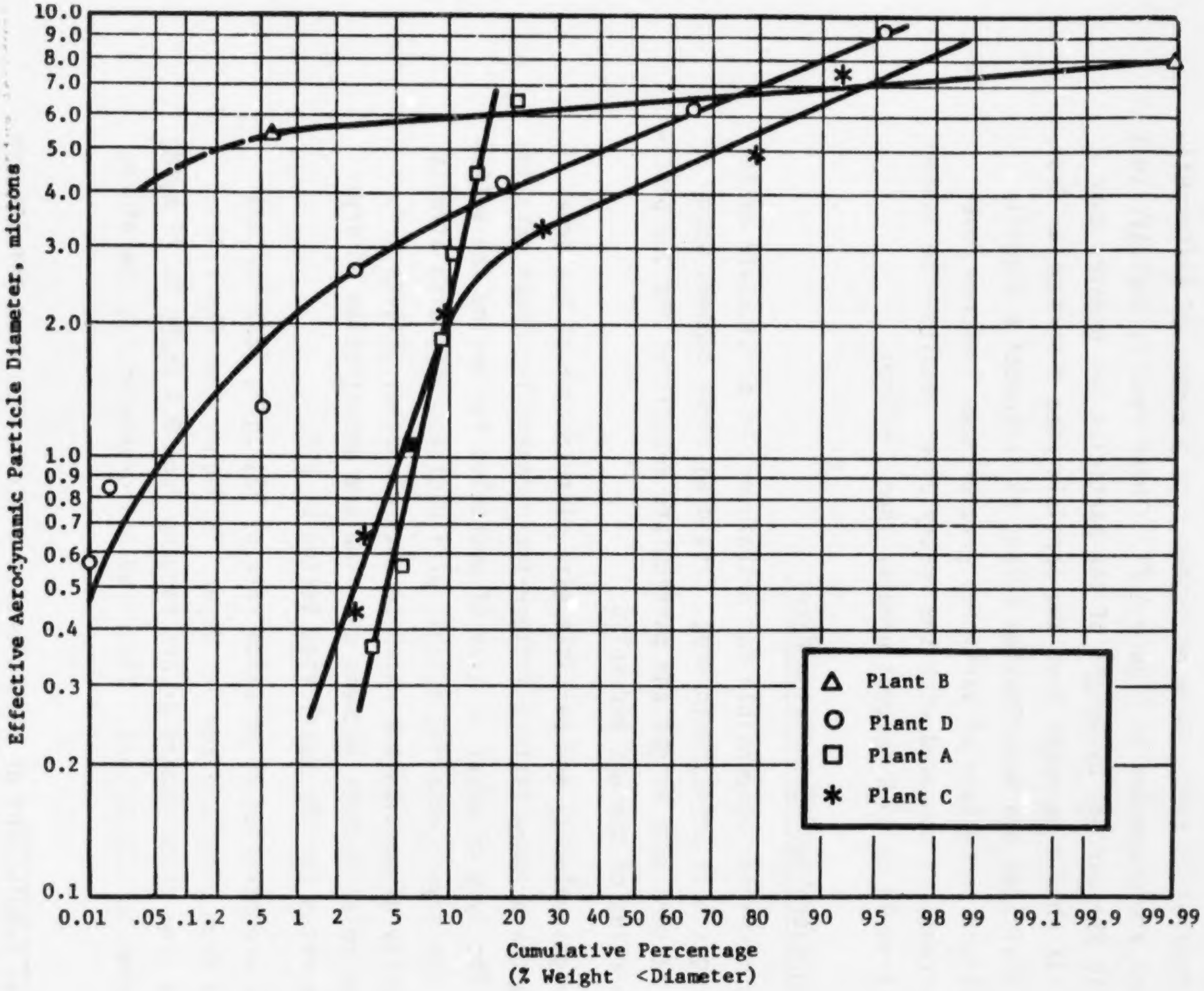

FIGURE 4-2
UNCONTROLLED AMMONIUM SULFATE DRYER EMISSIONS$^{2-5}$ PARTICLE SIZE DISTRIBUTION

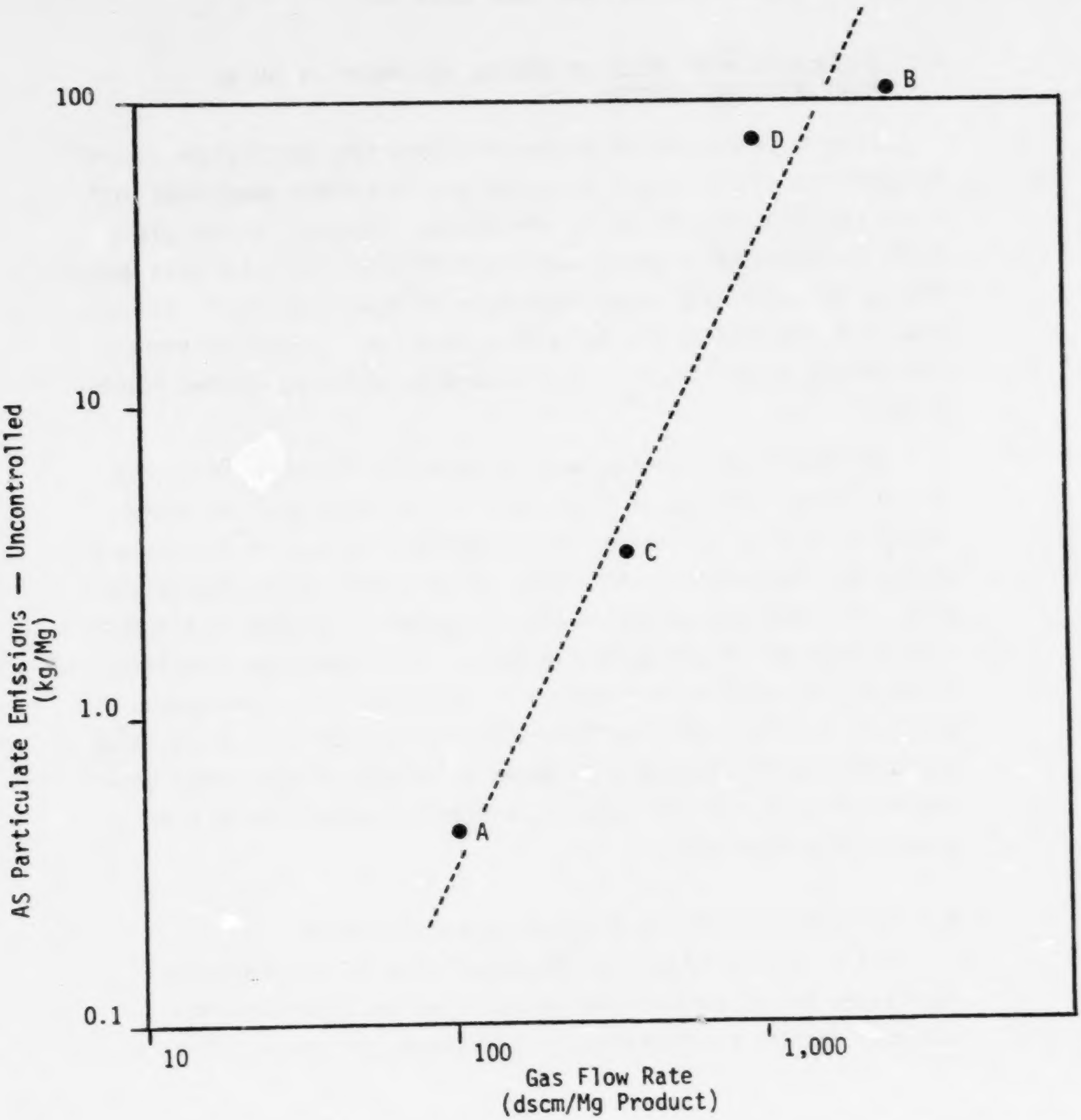

Figure 4-3. Uncontrolled AS Emissions Versus Gas Flow

appear to require more efficient control equipment in order to comply with air pollution regulations (see Table 3-3).

4.2 DISTRIBUTION OF EMISSION CONTROL EQUIPMENT IN THE AS MANUFACTURING INDUSTRY

In most cases, the incentive for installing particulate control equipment to collect dryer emissions was to achieve compliance with state and local air pollution regulations. However, at one plant using fluidized bed drying, the recent EPA test indicated that uncontrolled emissions are about 10 percent of dryer capacity.* In this situation, AS particulate emission control is required for process feasibility as well as for compliance with pollution control regulations.*

Scrubbers are commonly used to control particulate emissions in all segments of the AS industry. At the three existing caprolactam AS plants, wet scrubbers are employed to control particulate emissions. At synthetic AS plants wet scrubbers are predominately used. The only dry pollution control system in service is a fabric filter baghouse at one synthetic plant. For those coke oven facilities which dry or pneumatically convey AS, no emission control system is employed or relatively inefficient control devices such as cyclones are installed.** This data is based on surveys of nine steel companies which account for about 75 percent of total coke oven byproduct AS production.

4.3 WET SCRUBBING IN THE AMMONIUM SULFATE INDUSTRY

Wet scrubbing is used in the majority of AS manufacturing facilities for AS particulate removal from the dryer vent gas stream. Available information on performance of wet scrubbers in use by the AS manufacturing industry, is presented in Table 4-1. As indicated by the table, most of the scrubbers in use are of the low energy type with pressure drops equal to or less than 15.24 cm. (6 in.) WG. Very few of these scrubbers have been installed in recent years. Although many of these scrubbers are of the low energy type, they are adequate to meet present state and local air pollution regulations. Each type of scrubber commonly used in the industry including those which are candidates for "best demonstrated control technology" are discussed briefly in the following sections.

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*See Appendix C, Table C-4

**The cyclones are considered primarily as items of process equipment being used for product recovery, and therefore, they are not discussed as emission control equipment.

4.3.1 Venturi Scrubbers

The venturi scrubber is an air pollution control device in which the scrubbing liquid is atomized in a moving gas stream. Venturi scrubbers are used to control dryer emissions at some AS plants and in many particulate control applications in other industries. Collection efficiency is enhanced by three dominant factors: inertial impaction, condensation of water vapor on the particulate and in this application the high solubility of AS in water. In the venturi throat region, the gas velocity is considerably higher than that of the accelerating liquid. This causes the AS liquid solution to atomize into many fine droplets. Particulates impinge upon the slower moving liquid droplets by inertial impaction. Also, the dryer exhaust temperature and humidity of the gas promotes condensation of water vapor on the particulates. The increased wetness and weight of the particulates increases the probability of their impingement on wetted surfaces as a result of inertial impaction.

Two existing AS plants are known to employ venturi scrubbers to control particulate emissions--Plants B and D. Both units accept the full AS dryer particulate emission with no intermediate cyclones. Table 4-1 shows that the pressure drops and liquid-to-gas ratios are very similar. Pressure drops of the venturis at Plant B and Plant D are 25.4 dm. (10 in.) and 33.0 cm. (13 in.) WG, respectively. These

Table 4-1. AMMONIUM SULFATE INDUSTRY-SUPPLIED WET SCRUBBER PERFORMANCE DATA[a]

	Scrubber vendor	AS scrubber type	AS Production Rate Mg/hr (TPH)	Gas flow to scrubber sm^3/min (scfm)	Observed scrubber pressure drop cm H_2O WC (in H_2O WC)	Scrubber L/G ratio[g] liters/1000 m^3 (gal/1000 acf)
Plant F	Ducon	Centrifugal	---	---	12.7 (5)	308 (2.3)
	AAF[b]	Rotoclone[d]	---	---	12.7 (5)	348 (2.6)
	AAF	Rotoclone	---	---	12.7 (5)	415 (3.1)
Plant E	Ducon	Centrifugal[e]	---	1072 (37,900)	6.7 (13.4)	267 (2.0)
	Ducon	Centrifugal	---	410 (14,500)	4.5 (9.0)	267 (2.0)
Plant B	---	Venturi	---	810 (28,600)	25.9 (10.2)	3075 (23.0)
Plant H	NA[c]	Spray	19.1 (21)	144 (5100)	17.3 (6.8)	909 (6.8)
Plant G	NA	Packed Tower & NH_3 Condenser	19.1 (21)	242 (8560)	UK[f]	18,700 (140)
Plant I	NA	Packed Tower	14.7 (16)	73 (2585)	UK	2,311 (17.3)
Plant C	Ducon	Centrifugal	8.50 (9.34)	90 (3180)	15.2 (6)	267 (2.0)
	Ducon	Centrifugal	16.2 (17.8)	112 (3950)	15.2 (6)	267 (2.0)
Plant D	Heil	Venturi	8.4 (9.2)	85 (3000)	5.1 (13)	3,605 (26.9)

[a] All data supplied by industry in response to EPA 114 letter requests or from visits to AS production plants.
[b] American Air Filter.
[c] Not Applicable (not a standard design).
[d] Trade name of American Air Filter Co.
[e] Cyclones precede centrifugal scrubbers.
[f] Unknown.
[g] Scrubber liquid-to-gas-ratio.

Table 4-1. AMMONIUM SULFATE INDUSTRY-SUPPLIED WET SCRUBBER PERFORMANCE DATA (Concluded)

	AS particulate concentration		AS mass flow		AS mass discharge rate
	scrubber inlet mg/dsm^3 (gr/dscf)	scrubber outlet mg/dsm^3 (gr/dscf)	scrubber inlet kg/hr (lb/hr)	scrubber outlet kg/hr (lb/hr)	kg/Mg (lb/ton)
Plant F	--	220 (.096)	--	--	.14 (.27)
	--	57.2 (.025)	--	--	.036 (.071)
	--	708 (.309)	--	--	.40 (.79)
Plant E	--	87 (.038)	--	6.2 (12.4)	.22 (.44)
	--	48 (.021)	--	1.34 (2.67)	.11 (.22)
Plant B	28,500 (12.4)	10.4 (.005)	2100 (4200)	.5 (1.0)	.037 (.073)
Plant H	--	25.2 (.011)	--	.24 (.48)	.012 (.023)
Plant G	--	9.2 (.004)	--	.15 (.30)	.007 (.014)
Plant I		41.2 (.018)	--	.25 (.50)	.016 (.031)
Plant C	--	48.1 (.021)	--	.28 (.56)	.030 (.059)
	--	36.7 (.016)	--	.275 (.55)	.015 (.031)
Plant D	--	-- --	--	-- --	-- --

venturis are considered to operate in the low pressure drop range 12.7 to 50.8 cm. WG as compared with medium and high pressure drop venturi scrubbers which operate at 50 to 100 cm. WG and 100 to 150 cm. WG, respectively.[6]

The Plant D and Plant B units are both operated with high liquid-to-gas ratios (3605 and 3075 liters/1000M^3, respectively) as compared to liquid-to-gas ratios normally encountered in other industries, i.e., in the 900 to 1350 range.[7]. For a given venturi scrubber design, and with gas flow rate determined by the AS dryer operation, AS particulate collection efficiency becomes a function of liquid-to-gas ratio. The high liquid-to-gas values encountered in the Plant D and Plant B operations appear to be needed to ensure high AS particulate efficiency, especially for the smaller particle sizes.

Company-supplied emission test data on the Plant B venturi scrubber are summarized in Table 4-1. The test appears to have been performed using the EPA Method 5 procedure. Based on test measurements of both scrubber inlet and outlet, the average collection efficiency is 99.96 percent. The data also show low scrubber outlet AS particulate concentration of 10.4 mg/dscm (0.005 gr/dscf) and 0.04 kg/Mg of AS production. A 25 percent AS solution was used as scrubbing liquid. Although this test was conducted at approximately 50 percent of the maximum AS production rate, the collection efficiencies are similar to those measured during a period of full production. Results of recent EPA emission test values obtained on this scrubber as well as the Plant D venturi scrubber are presented in Section 4.5.

4.3.2 Centrifugal Scrubbers

Centrifugal scrubbers are employed at a number of AS plants to control dryer emissions. Particulate-laden gas usually enters the scrubber tangentially, imparting a spinning motion to the gas. The

AS particulates are captured by their impacting on droplets of water or weak AS solution and/or by their contact with wetted surfaces. For some types of scrubbers, collection efficiency is enhanced by directing the gas against rotating vanes. The pressure drops reported from AS plants range from 7.6 cm. to 33.0 cm. (3 to 13 in.) WG (see Table 4-1). However, higher pressure drops for centrifugal scrubbers do not necessarily imply higher efficiencies. Efficiencies vary widely among different types of centrifugal scrubbers.

Ducon centrifugal scrubbers are employed at two of the three existing caprolactam AS plants. The Ducon Company UW-4 scrubber is reported to be capable of achieving higher removal efficiencies than their UW-3 centrifugal scrubber. Collection efficiency for the UW-3 is estimated to be about 95 percent for particulates 3 micron in diameter and larger. Collection efficiencies for the UW-4 are estimated to be about 98 percent for particulates greater than 1 micron.[8]. Energy requirements are generally lower than those of venturi scrubbers.

Industry-supplied emission test data are available on centrifugal scrubbers (all with a liquid-to-gas ratio of approximately 267 liters/1000M^3) employed for AS particulate control at various AS production plants (see Table 4-1). Scrubber outlet grain loadings vary from a low of 36 mg/dscm (0.016 gr/dscf) to a high of 660 mg/dscm (0.294 gr/dscf); mass emissions varied from 0.07 to 0.35 kg/Mg of AS production. There are no scrubber inlet data available so that scrubber efficiencies cannot be determined. It is not known how closely EPA Method 5 test procedures were followed for many of the tests. EPA emission tests were recently conducted on one of these centrifugal scrubbers with the results shown in Section 4.5.

4.3.3 Rotoclones

Type "N" Rotoclones (a trade-name of American Air Filter Corp.) are employed at one AS production plant and in similar applications in other industries. Particulate-laden gas is ducted through a stationary impeller at high velocity, forcing the scrubber liquor to form a turbulent sheet. The centrifugal force, exerted by rapid changes in the direction of flow, causes the AS particulates to impinge on the turbulent sheet. Vendor design efficiency data indicate that general particulate collection efficiency typically ranges from 93 to 99.3 percent for particulates 3 micron in diameter for type "N" Rotoclones with pressure drops of 15.24 to 28 cm. (6 to 11 in.) WG and high liquid-to-gas ratios.[9]

As indicated in Table 4-1, data are available on two "Type N" Rotoclones. Pressure drop in both these units is given as 12.7 cm. (5 in.) WG. However, the liquid-to-gas ratio involved in these two AS scrubbing operations is difficult to determine, since the liquid circulation is entirely internal. Scrubber outlet grain loadings showed a ten-fold variation ranging from 68 mg/dscm (0.03 gr/dscf) to 704 mg/dscm (0.31 gr/dscf). Mass emissions varied from 0.03 to 0.35 kg/Mg of AS production. It is not known how closely EPA Method 5 test procedures were followed in these tests.

4.3.4 Packed Tower Scrubbers

Only two packed tower scrubbers are known to be in use at AS plants (see Table 4-1). Neither of these units appears to be standard design. Collection efficiency depends on the liquid-to-gas ratio, pressure drop, and other factors. Pressure drops are commonly about 4.0 cm. WG/Meter (0.5 in. WG/ft) of packing.[10] One plant which designed its own packed tower scrubber reports an estimated collection efficiency of less than 90 percent.[11] At another plant a spray chamber scrubber is used in series after a packed tower scrubber. Collection efficiency of properly designed packed tower scrubbers is comparable with other low-energy-type scrubbers.

4.3.5 Spray-Type Scrubbers

Spray-type scrubbers are used at several older AS plants to collect AS particulate (Table 4-1). Spray nozzles are used to atomize the liquid to form fine droplets. The pressure drop is relatively low, usually 2.5 cm to 5.0 cm. (1 to 2 in.) WG, and the operating costs are minimal. Collection efficiencies of the spray-type of contact scrubber are usually not competitive with medium and high energy scrubbers. Efficiencies for most types of 2 micron particulates are typically near 75 percent.[12]

4.4 FABRIC FILTRATION IN THE AMMONIUM SULFATE INDUSTRY

All fabric filters (baghouses) operate in basically the same way; dirty gas is ducted to the unit where it is filtered by cloth tubes or bags. This filtering action is extremely efficient and results normally in better than 99 percent of the entrained particles being removed by the bags. The bags must be periodically purged of this collected material. The method and frequency of cleaning differentiates one type of baghouse from another.

Only one domestic AS producer employs a baghouse for AS particulate control--Plant A. This firm uses a Carter-Day baghouse, Model 24RJ60, with a reverse jet cleaning mechanism. The unit has 30 m^3 (320 ft^2) of filter cloth which comprises 24 bags. The filter medium employed is Dacron® felt, which is reported to have good acid resistance and flex abrasion.[13]

At Plant A, the exhaust gas from the dryer passes directly to the baghouse, through the filters, to a blower, and out the stack. At the operating gas flow rate of approximately 35 m^3/min (1250 acfm) the gas-to-cloth (GC) ratio of this baghouse is 4.* This ratio appears to be somewhat lower than in other industries using felted bags.[14]

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*The basic design parameter used in specifying any baghouse for any application is the gas-to-cloth ratio, defined as the ratio of actual gas-flow to net cloth area. Thus,

$$GC = I/A$$

where GC = gas-to-cloth ratio in feet/minute
I = volumetric gas flow in acfm
A = net cloth area in square feet

At Plant A, the dryer exhaust gas temperature ranges from ambient* to 80°C (176°F), with an average operating temperature of about 54°C (135°F). Due to the baghouse GC constraint on the gas flow rate, the ratio of dryer exhaust gas to product rate is significantly lower than most other dryers used by the industry.** This low flow rate appears to be compensated by the low moisture content and high sensible heat content of the feed entering the dryer.

While the baghouse at this plant represents one of the most efficient types of particulate collection devices, it should also be noted that the plant operates only intermittently and encounters frequent operational problems associated with the use of the fabric filter system.

In spite of the fact that insulation covering the ductwork and baghouse minimizes temperature drop in the dryer exhaust gas, the following evidence indicates that the temperature of the dryer exhaust and/or baghouse surfaces were not maintained sufficiently above the dew point at all times:***

1. AS accumulations on the inside wall of the inlet ducts.
2. Periodic baghouse shutdown for bag removal, laundering, and reinstallation (every 30 days).
3. Daily flushing of the cone discharge section of the bag house with water.

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*During hot weather it is reported that the dryer is sometimes operated with burner shutoff, in effect operating the dryer as an evaporative cooler.

**The baghouse in use at Plant A was originally designed for another application; the maximum allowable design gas flow rate to this unit is appreciably lower than the normal direct-fired dryer gas flow (see Table 3-7).

***Based on a measured 13 percent water vapor concentration in the dryer exhaust at this plant,[15] the dew point of the exhaust gas stream is estimated to be about 51° (123°F).

Although fabric filters are susceptible to condensation problems, maintaining the temperatures of all surfaces above the dew point would probably alleviate bag blinding and the associated problems listed above. It is likely, however, that maintaining baghouse temperatures above the dew point may require more energy than would ordinarily be required to operate the dryer.

Currently there is no data available regarding the use of fabric filter particulate control systems on caprolactam by-product AS plants. However, at the one caprolactam by-product plant tested by EPA, results show that most of the hydrocarbon (HC) emissions from the AS dryer (about 94 percent) are present in the vapor phase at the exit gas temperatures involved, about 85°C. At this operating temperature condensation of caprolactam vapor should be minimal and it is unlikely that blinding* would occur.[16,17,18,19]

4.5 EPA EMISSION TEST DATA

Based on a survey of the AS production industry which included visits to all three caprolactam AS plants, four synthetic AS plants and two coke oven AS plants, it was determined that very few plants met the criteria for AS particulate emission testing. These criteria included:

- Best demonstrated control technology
- Reasonably nonturbulent flow field
- Accessibility of control equipment ports
- Control equipment age and/or condition
- Availability of ports and support scaffolding
- Representative plant capacity

Best demonstrated control technology was determined based on an evaluation (in the case of wet scrubbers) of available data on scrubber pressure drop and liquid-to-gas ratio as well as the types of wet scrubbers in use in the industry. Three plants with wet scrubbers (including one caprolactam AS plant and two synthetic AS plants) were chosen for emission testing based on consideration of all of the above factors. The one dry AS particulate control system in use (baghouse) was chosen for testing since it represents a unique application of this control method in the AS manufacturing industry. Table 4-2 lists those facilities which have been tested together with the control equipment in use.

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*The embedded "dust" blinds or plugs the fabric pores to such extent that the fabric resistance become permanently excessively high. Excessive resistance results in high operating energy requirements for the system.

Emission testing was carried out by EPA contractors at each of facilities A through D using EPA Method 5 to determine AS particulate emission rates and grain loading at the inlet and outlet of each of the control devices. In addition, caprolactam inlet and outlet emission levels were determined at Plant B. At all of the facilities

Table 4-2. AS PARTICULATE CONTROL SYSTEMS TESTED BY EPA

Plant Designation	Controlled Facility	Control Technology In Use
A	Rotary Dryer	Baghouse
B	Fluid Bed Dryer	Venturi Scrubber
C	Rotary Dryer	Centrifugal Scrubber
D	Rotary Dryer	Venturi Scrubber
E	Fluid Bed Dryer	Cyclones and Centrifugal Scrubber

*This was a company-sponsored emission test; the EPA Method 5 procedure used by the test contracter has been accepted by EMB.[20]

tested by EPA, particle size distributions were determined for AS particulate at the inlet to the respective control devices.

Detailed tabulations of AS emission test results are presented in Appendix C, Tables C-1 through C-10. Detailed tabulations of caprolactam concentrations and emission rates, which are determined at Plant B, are presented in Appendix C, Tables C-11 and C-12. Detailed tabulations of particle size distributions determined at the four facilities tested are presented in Appendix C, Tables C-13 through C-16. Detailed tabulations of the observed opacities for the four plants tested are given in Tables C-17 through C-20. Summarized descriptions of each of the facilities tested are presented in Appendix C.

The emission tests at facilities A through D are presented in terms of calculated controlled AS grain loadings in Figure 4-3 and calculated controlled mass emission rates in Figure 4-4. Averages of this test data together with available industry data, the latter believed to be the result of valid EPA Method 5 testing, are shown in Figures 4-5 and 4-6 on grain loading and mass emission bases, respectively.

The AS particulate emission results calculated in terms of a mass emission rate (Figures 4-4 and 4-6) are based on an indirect determination of dryer process weight rate, since all existing plants visited and/or tested except one (Plant D) have no AS dryer product weigh scales. Additionally, it was indicated that Plant D's weigh scale was not reliable so that AS production was based on metered sulfuric acid consumption to the process. A discussion of methods and accuracy of AS production rate, indirectly determined at the plants tested, is presented in Appendix E.

Of the six data points shown in Figures 4-5 and 4-6, five represent wet scrubber operation, with two of these points representing the Plant B venturi scrubber. In the EPA test this scrubber achieved an average controlled grain loading of 0.046 g/dscm (0.021 gr/dscf), an average mass emission rate of 0.16 kg/Mg, and an average

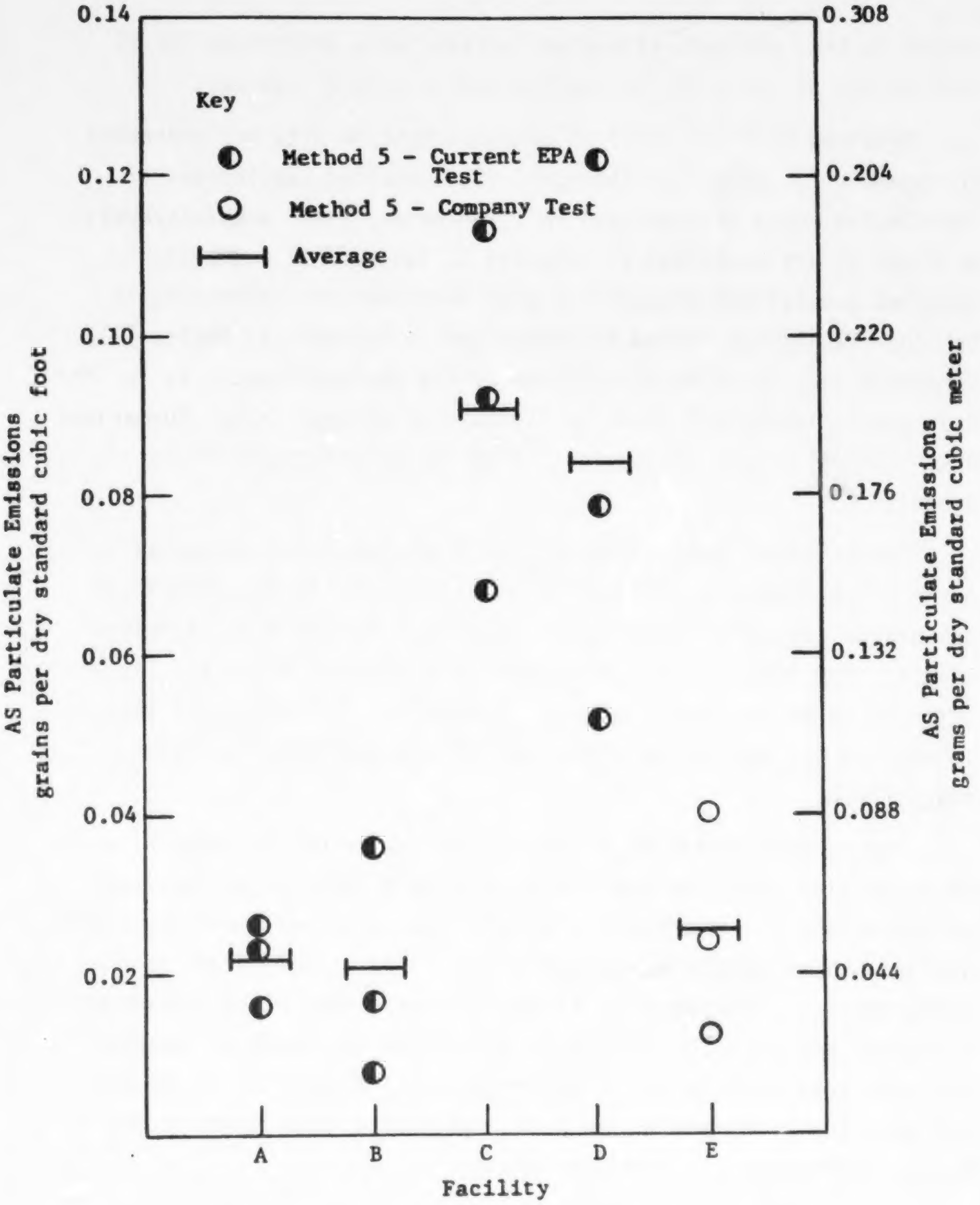

FIGURE 4-4
CONTROLLED AS PARTICULATE EMISSIONS FROM EPA EMISSION TESTS—CALCULATED GRAIN LOADINGS

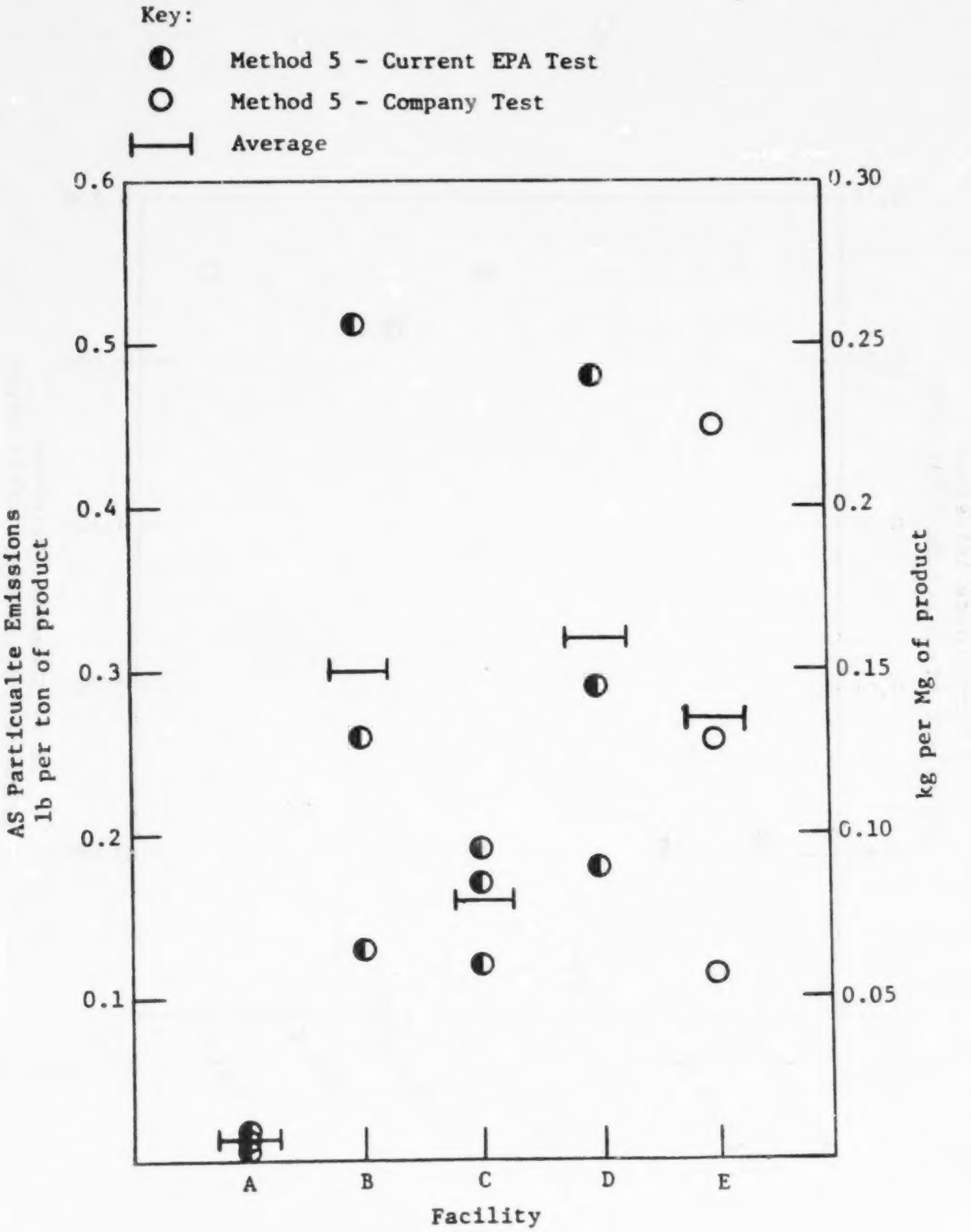

FIGURE 4-5
CONTROLLED AS PARTICULATE EMISSIONS FROM EPA EMISSION TESTS—CALCULATED MASS EMISSION RATES

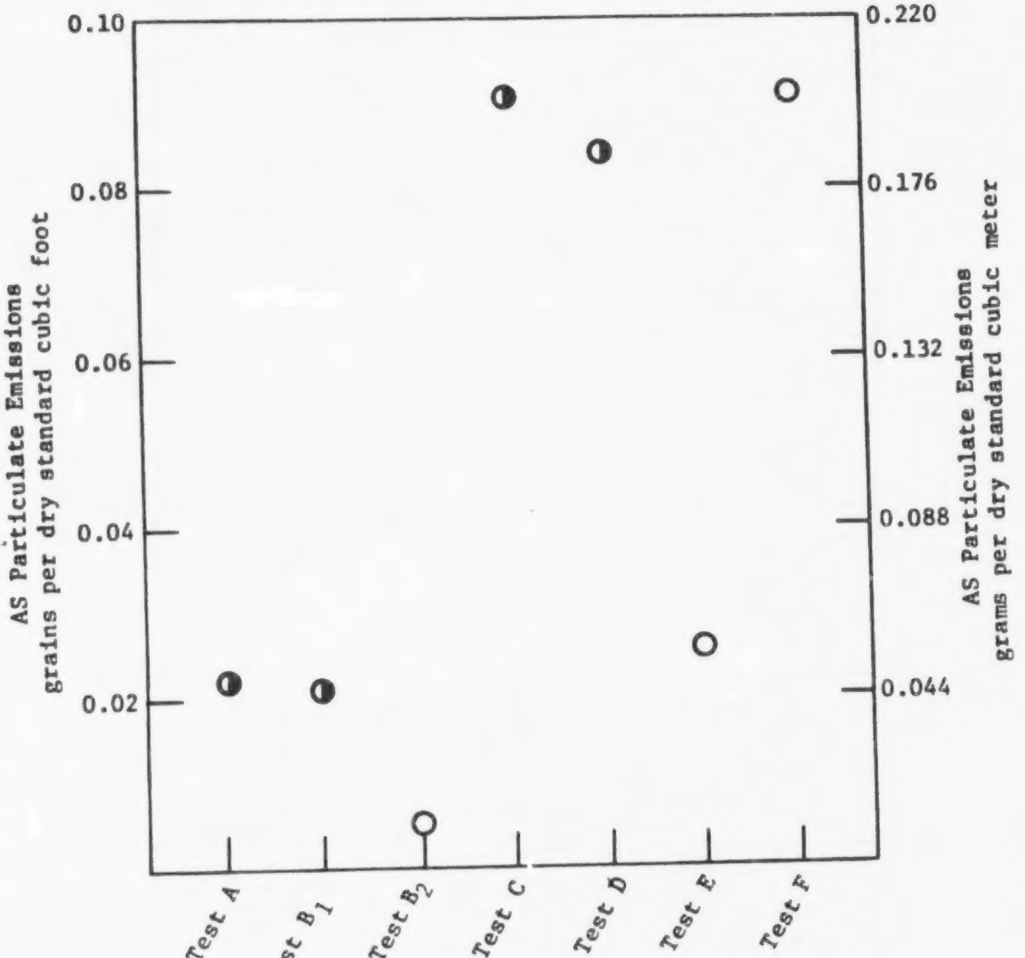

FIGURE 4-6
AVERAGE CONTROLLED AS GRAIN LOADING TEST DATA—
EPA METHOD 5

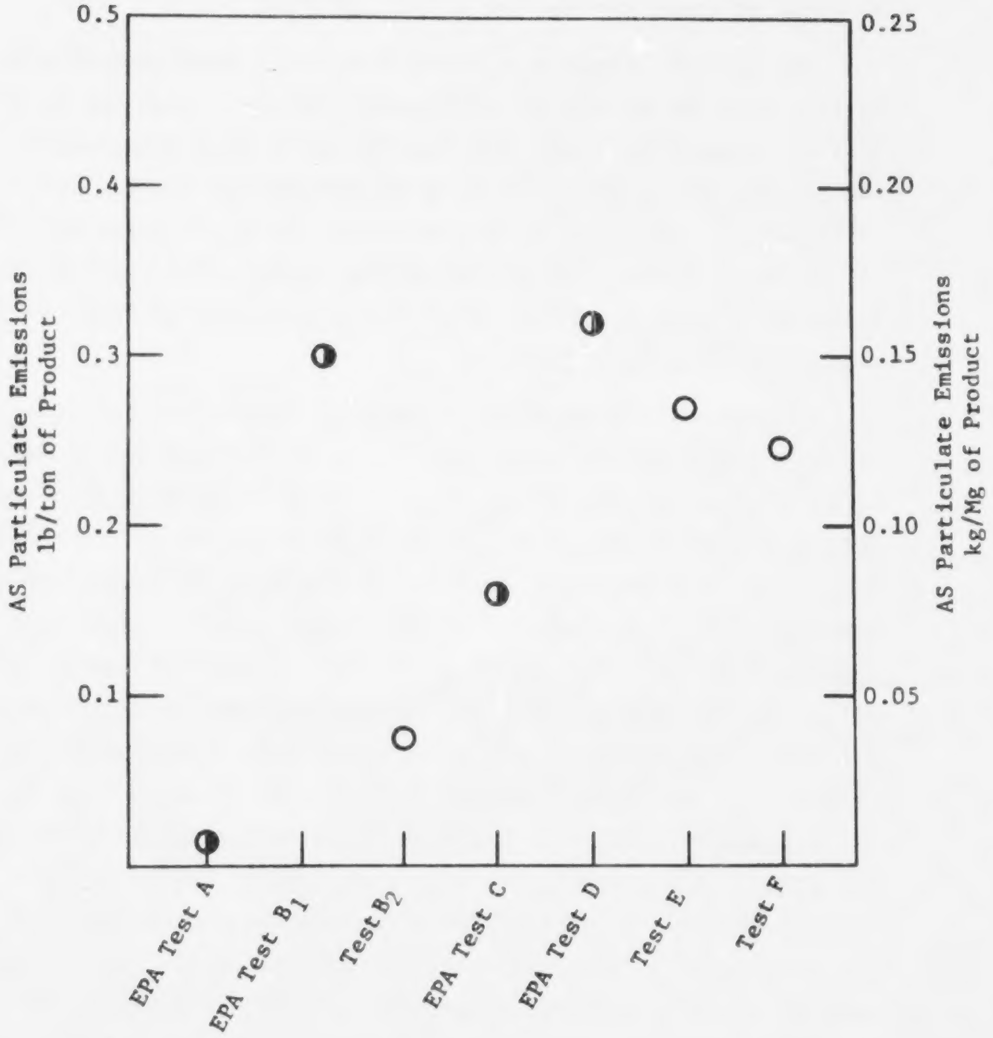

FIGURE 4-7
AVERAGE CONTROLLED AS MASS EMISSION RATE DATA—
EPA METHOD 5

collection efficiency of 99.85 percent when operating at close to full plant capacity. The emission test conducted by the company reported a 0.011 g/dscm (0.005 gr/dscf) grain loading and a mass emission rate of 0.04 kg/Mg of AS production at an average efficiency of 99.98 percent. As mentioned earlier, however, this result was obtained at about one-half of plant capacity.

The venturi scrubber at Plant B has also been demonstrated to collect over 88 percent of caprolactam emissions from the AS dryer. This percentage is higher than that based on test data supplied by the company which indicated 50 to 60 percent caprolactam collection efficiency.[21] At Plant B, 94 percent of the caprolactam emissions in the dryer exhaust are in the gaseous state. The caprolactam emissions coming out of the stack are also mostly gaseous--97 percent measured in the vapor phase.

Two sets of baghouse outlet emission tests were conducted at Plant A, since the first set of tests were rejected due to discovery of some defective bags which resulted in an abnormally high grain loading result. The second set of baghouse outlet tests resulted in an average mass emission rate of 0.007 kg/Mg of AS production and an average 0.022 gr/dscf grain loading. Coupled with the average inlet results from the first set of tests, the baghouse showed a collection efficiency of 98.7 percent. This efficiency was somewhat lower than expected since baghouses are normally capable of 99+ percent efficiency. Of the factors influencing emission rates at Plant A, one is most significant. The baghouse in use was originally designed for another application; the maximum allowable design gas flow rate to this unit is appreciably lower than normal direct-fired gas flow. The constraint on gas flow rate, by restricting the ratio of dryer exhaust gas-to-product rate, results in a significantly lower uncontrolled inlet emission rate than most other dryers used in the industry. The fabric filter inlet uncontrolled emission rate was 0.41 kg/Mg of production. Those of facilities controlled by venturi scrubbers were 110 kg/Mg and 77 kg/Mg. This represents an uncontrolled mass emission difference in the range of two orders of magnitude.

Facility D, a synthetic AS plant with a rotary drum dryer, is controlled by a venturi scrubber operating at a pressure drop of 33 centimeters (13 inches W.G.) and a L/G ratio of 3,600 liters/1000 m^3 (27 gallons per 1000 acf). Analysis of EPA test results at Plant D show a high uncontrolled emission rate entering the control device; the control system did however demonstrate the typically high control efficiency (99.8 percent) achievable with a venturi scrubber. The outlet emission rate, 185 milligrams per dry standard cubic meter and 0.158 kg/Mg of product, was affected by the high inlet emission load caused by a process variation at Plant D. It was indicated that the crystallizer at Plant D periodically goes into a fines cycle, lasting anywhere from 10 to 15 hours, during which time a much heavier proportion of AS fines is produced in the dryer product than is normal.

Test E (the industry-supplied outlet grain loading result for which an emission test report was available), shown in Figure 4-5, represents a low-energy wet scrubber--a centrifugal scrubber operating at a nominal ΔP of about 23 cm. (9 in.) WG and an liquid-to-gas ratio of 267 liters/1000m^3.[22] It should be noted that this unit operates downstream from a set of cyclones which remove a significant portion of the AS particulate from the dryer vent gas prior to treatment in the wet scrubber. Additionally, no opacity during a preliminary screening of this plant was noted to be at least 10 percent.[23]

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14. Ibid, p. 288.

15. Op. Cit., Ref. 2, p. 20.

16. Information provided by Dow-Badische, Company in a telephone conversation between R. Ray and R. Zerbonia, PES, April 19, 1979.

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5. MODIFICATION AND RECONSTRUCTION

5.1 BACKGROUND

Upon promulgation, NSPS apply to all affected facilities that are constructed, modified, or reconstructed after the date of proposal. On December 16, 1975, the Agency promulgated amendments to the general provisions of 40 CFR Part 60 including additions and revisions to clarify modification and the addition of a reconstruction provision. Under these provisions, 40 CFR 60.14 and 60.15, respectively, an "existing facility" may become subject to standards of performance if deemed modified or reconstructed. An "existing facility" defined in 40 CFR 60.2 (aa), is an apparatus of the type for which a standard of performance is promulgated and the construction or modification of which was commenced before the date of proposal of that standard. The following discussion examines the applicability of the modification/reconstruction provisions to the affected facility (the AS dryer) and details conditions under which existing facilities could become subject to standards of performance. Section 5.2 examines the general provisions applicable to modification and reconstruciton. Section 5.3 relates these provisions to the AS industry and process dryer. The enforcement division of the appropriate EPA regional office should be contacted regarding any questions on modification or reconstruction applicability.

5.2 40 CFR PART 60 PROVISIONS FOR MODIFICATION AND RECONSTRUCTION

5.2.1 Modification

§60.14 defines modification as follows:

> ". . ., any physical or operational changes to an existing facility which results in an increase in the emission rate to the atmosphere of any pollutant to which a standard applies shall be considered a modification within the meaning of section 111 of the Act. Upon modification, an existing facility shall

become an affected facility for each pollutant to which a standard applies and for which there is an increase in the emission rate to the atmosphere."[1]

Paragraph (e) lists certain physical or operational changes which by themselves are not considered modifications. These changes include:

a. Routine maintenance, repair, and replacement.
b. An increase in the production rate not requiring a capital expenditure as defined in 60.2(bb).
c. An increase in the hours of operation.
d. Use of an alternative fuel or raw material if prior to the standard, the existing facility was designed to accommodate that alternate fuel or raw material. (Conversion to coal, as specified in 111(a)(8) of the Clean Air Act, is also exempted.)
e. The addition or use of any system or device whose primary function is the reduction of air pollutants, except when an emission control system is removed or replaced by a system considered to be less efficient.
f. The relocation or change in ownership of an existing facility.

Paragraph (b) clarifies what constitutes an increase in emissions in kilograms per hour and the procedures for determining the increase including the use of emission factors, material balances, continuous monitoring system and manual emission tests. Paragraph (c) affirms that the addition of an affected facility to a stationary source does not make any other facility within that source subject to standards of performance. Paragraph (f) simply provides for superseding any conflicting provisions.

5.2.2 Reconstruction

§60.15 regarding reconstruction states:

> "An existing facility shall be considered an affected facility by the Administrator upon reconstruction through

> the replacement of a substantial majority of the existing facility's components irrespective of any change of emission rate. The owner or operator may request the Administrator to determine whether the proposed reconstruction involves replacement of a substantial portion of the existing facility's components based on the capital cost of all new construction and other technical and economic considerations."[2]

The purpose of this provision is to ensure that an owner or operator does not perpetuate an existing facility by replacing all but vestigial components, support structures, frames, housing, etc., rather than totally replacing it in order to avoid subjugation to applicable standards of performance. As noted, upon request EPA will determine if the proposed replacement of an existing facility's components constitutes reconstruction.

5.3 APPLICABILITY TO AMMONIUM SULFATE PLANTS

5.3.1 Modification

Investigation of the AS industry has shown that there are no actions or changes, either physical or operational, applicable to the AS dryer that would qualify as a modification. There are, however, potential actions or changes which may increase AS emissions but are not to be considered as modifications to existing AS dryers, irrespective of any change in the emission rate.

5.3.1.1 Maintenance, Repair, and Replacement

Maintenance, repair and component replacement which are considered routine for a source category are not considered modifications under §60.14 (e)(1). An increase in emissions is not expected to occur as a result of normal maintenance or replacement of AS dryer components.

Routine maintenance would involve periodic cleaning out of accumulated deposits of AS on the dryer walls and lubrication of moving parts such as the drive gears and trunnion rolls on a rotary dryer and motor drives on air blowers. Routine maintenance should not have any noticeable effect on dryer emissions.

Several dryer components can be expected to require replacement as a matter of routine due to the unit being in continuous service for long periods of time. These components may include the oil or gas firing nozzles supplying heat to direct-fired rotary dryers, fan blades in the air blowers, and drive gears and trunnion rolls on rotary dryers. Replacement with equivalent components should not affect emissions and would be considered exempt under §60.14(e)(1).

5.3.1.2 Alternative Fuel

The use of an alternative fuel would not be considered a modification if the existing facility was designed to accommodate the alternative. In the case of a direct-fired rotary dryer originally designed to use oil or gas as fuel, the substitution of oil for gas would be considered exempt under §60.14(e)(4).

5.3.1.3 Addition of a System to Control Air Pollutants

The addition or use of any system or device whose primary function is to reduce air pollutants, except the replacement of such a system or device by a less efficient one, is not by itself considered a modification under §60.14. For example, the replacement of a relatively inefficient cyclone with a venturi scrubber in an existing dryer installation, for the purpose of reducing AS particulate that would otherwise be emitted to the atmosphere, would not be considered a modification under §60.14(e)(5).

5.3.1.4 Increase in Production Rate Without a Capital Expenditure

An increase in production rate of an existing facility is not in and of itself a modification under §60.14 if the increase can be accomplished without incurring a capital expenditure on the plant containing the affected facility.*

Ammonium sulfate dryers are generally overdesigned for recommended throughput.[3] It is possible for an AS production plant to increase the amount of AS throughput in the dryer and still achieve the required amount of moisture removal. This increase in the dryer production rate would not be considered a modification under §60.14(e)(2). If the need for increased capacity requires a capital expenditure to modify the dryer, then that dryer may be considered a modification under this section. Should expansion of AS plant capacity require a new dryer, then the new dryer would be considered an affected facility subject to the NSPS.

5.3.1.5 Equipment Relocation

Relocation of a dryer within the same plant would not constitute a modification.

5.3.1.6 Removal or Disabling of a Control Device

The intentional removal or disabling of any emission control component of an existing dryer installation which would cause an increase of emissions would be a modification. An existing facility that is modified becomes an affected facility subject to the NSPS.

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*Capital expenditure is defined as "an expenditure for a physical or operational change to an existing facility which exceeds the product of the applicable annual asset guideline repair allowance percentage specified in the latest edition of Internal Revenue Science Publication 534, and the existing facility's basis, as defined by Section 1012 of the Internal Revenue Code." (40 CFR 60, Sect. 60.2[bb]).

The reconstruction provision (§60.15) is applicable only where an existing facility is extensively rebuilt. Determination is based on the capital cost of all new construction and other technical and economic considerations. An action that would be construed as reconstruction of an AS dryer is the replacement or extensive rebuilding of the dryer shell and internals.

Ammonium sulfate dryers are expected to have a useful life of 25 years, on the average.[4] It is not believed practical to attempt major reconstruction of these since the costs involved would be comparable to those for new units, and considerable plant downtime could be involved. The usual practice is to replace the entire unit at this point.[5] The new AS dryer would then be subject to the NSPS.

5.4 REFERENCES

1. U.S. Environmental Protection Agency. Code of Federal Regulations (CFR), Title 40, Protection of Environment, Section 60.2 (h), Definitions. Office of the Federal Register. Washington, D.C., revised as of July 1, 1977. p. 6.

2. U.S. Environmental Protection Agency. Code of Federal Regulations (CFR), Title 40, Protection of Environment, Section 60.15, Reconstruction. Office of the Federal Register. Washington, D.C., July 1, 1977. p. 18.

3. Data provided by C-E Process Equipment, Bartlett-Snow Division, Chicago, Illinois, in a telephone conversation between Fred Aiken and Marvin Drabkin of the MITRE Corporation, Metrek Division, on January 2, 1979.

4. Ibid., Reference 3.

5. Ibid., Reference 3.

6.0 MODEL PLANTS AND REGULATORY ALTERNATIVES

The purpose of this chapter is to define model plants and identify regulatory alternatives. Model plants are parametric descriptions of the types of plants that, in EPA's judgment, will be constructed, modified, or reconstructed. The model plant parameters are used as a basis for estimating the environmental, economic, and energy impacts associated with the application of the regulatory alternatives (ways in which EPA could regulate emissions from AS dryers) to the model plants.

6.1 MODEL PLANTS

Since the dryer is the only significant emission source in the AS industry, each AS model plant refers to a specific combination or set of dryer operating conditions. Therefore, in this case, a model plant may be more appropriately called a "model dryer."

Each AS manufacturing sector is unique from a technical standpoint. Dryer types and sizes, gas-to-product flow rates, and uncontrolled particulate emission rates vary from one sector to another and often within each sector. For this reason, it was apparent that no single model plant (or dryer) could adequately characterize the AS industry. Accordingly, several model plants were specified in terms of the appropriate parameters.

Table 6-1 lists model dryer parameters used in the environmental, energy, cost and economic analysis for each industry category: caprolactam AS, synthetic AS and coke oven AS. Each industry sector is represented by a single plant size consisting of one or more dryers. Because the gas-to-product ratio varies considerably between AS dryers, four different gas-to-product ratios were selected to represent each industry category. Each of the four (4) gas-to-product ratios applies to the three industrial categories. In addition, another model plant with a slightly larger dryer and higher gas flow rate has been incorporated in order to make the caprolactam by-product sector model plants

Table 6-1. MODEL PLANT PARAMETERS FOR AMMONIUM SULFATE DRYERS

Case	Industry Segment	Ammonium Sulfate Production Capacity Per Dryer		Number of Control Systems	Number and Type of Dryers	Dryer Gas Exhaust Rate[c] Per Dryer Unit				Particulate Emission Rates Per Dryer: No Control[d]		SIP Regulation[e]		OPTION II Mass Format[f]		OPTION II Conc Format[g]	
		Mg/h	(tons/h)			Nm^3/min	(dscfm)	m^3/min	(acfm)	kg/h	(lb/h)	kg/h	(lb/h)	kg/h	(lb/h)	kg/h	(lb/h)
1	Caprolactam	27.2	(30)	2	2IF[a]	1216	(42,500)	1500	(52,900)	2487	(6270)[h]	18.2	(40.0)	4.1	(9.0)	3.31	(7.29)[h]
2		22.7	(25)	2	2DF[b]	58.9	(2,083)	71.5	(2,529)	40.5	(89.3)	16.1	(35.4)	3.4	(7.5)	0.16	(0.36)
3		22.7	(25)	2	2DF,IF	235.8	(8,333)	294.0	(10,383)	162	(357)	16.1	(35.4)	3.4	(7.5)	0.65	(1.43)
4		22.7	(25)	2	2IF	589.6	(20,833)	735.0	(25,958)	405	(893)	16.1	(35.4)	3.4	(7.5)	1.62	(3.57)
5		22.7	(25)	2	2IF	943.3	(33,333)	1184.0	(41,533)	647	(1427)	16.1	(35.4)	3.4	(7.5)	2.59	(5.71)
6	Prime	13.6	(15)	1	2DF	35.4	(1,250)	44.1	(1,558)	24.3	(53.5)	11.4	(25.2)	2.0	(4.5)	0.10	(0.21)
7		13.6	(15)	1	1DF,IF	141.5	(5,000)	176.3	(6,230)	97	(214)	11.4	(25.2)	2.0	(4.5)	0.39	(0.86)
8		13.6	(15)	1	1IF	353.8	(12,500)	440.8	(15,575)	243	(535)	11.4	(25.2)	2.0	(4.5)	0.97	(2.14)
9		13.6	(15)	1	1IF	566.0	(20,000)	705.2	(24,920)	388	(856)	11.4	(25.2)	2.0	(4.5)	1.55	(3.42)
10	Coke Oven	2.7	(3)	1	1DF	7.1	(250)	8.8	(312)	4.8	(10.7)	3.9	(8.6)	0.4	(0.9)	0.02	(0.04)
11		2.7	(3)	1	1DF,IF	28.3	(1,000)	35.3	(1,246)	19.4	(42.8)	3.9	(8.6)	0.4	(0.9)	0.08	(0.17)
12		2.7	(3)	1	1IF	70.8	(2,500)	88.2	(3,115)	48.5	(107)	3.9	(8.6)	0.4	(0.9)	0.20	(0.43)
13		2.7	(3)	1	1IF	113.2	(4,000)	134.4	(4,784)	78.0	(172)	3.9	(8.6)	0.4	(0.9)	0.31	(0.69)

[a] Indirect-fired, usually by steam heated air.

[b] Direct-fired, usually by natural gas.

[c] Based on dryer exhaust conditions of 79°C (175°F) and 4 percent by volume water vapor.

[d] Back-calculated from controlled outlet emission rates; based on the particulate removal efficiency of 99.6 percent.

[e] Allowable emission rate under process weight regulation of a typical SIP; calculated from equation: lb/h emissions = 4.10 $(P)^{0.67}$, where P is the process rate expressed in tons/h.

[f] Based on a controlled emission rate of 0.15 kg/Mg (0.3 lb/ton) of AS Production.

[g] Based on a controlled emissionrate of 0.05 g/m^3 (0.02 gr/dscf) of exhaust gas.

[h] Values determined from actual plant tests in which exhaust gas flows and particulate concentrations for a medium-energy venturi scrubber were measured.

more representative of the AS industry. This yields a total of 13 model plant or dryer cases.

The selection of the model dryer production rates and gas flows is based on published literature, information obtained during plant visits, and responses to EPA requests for information. The selected production rates in Table 6-1 are very close to the average values shown in Table 3-2 except for the caprolactam AS category. This category is represented by two AS dryers, each having a capacity of 22.7 Mg/hr (25 tons/hr); total capacity is 45.4 Mg/hr. The gas-to-product ratios in Table 6-1 range from 142 to 2260 meters per ton (5,000 to 80,000 dscf/ton), a range which applies to nearly all dryers found in the AS industry. In Table 6-1, the actual gas flow rates were computed from the standard gas flow rates by assuming a temperature of 80°C (175°F), a pressure of 760 mm Hg (1 atmosphere), and a moisture content of 4 percent. A range of gas flows is used to characterize either a rotary drum dryer or a fluidized bed dryer because either dryer type could be used with a new plant. Air flows assumed for the cost and economic impact analysis include 565 m^3/Mg (20,000 dscf/ ton) for indirect-fired rotary dryers and 2260 m^3/Mg (80,000 dscf/ton) for indirect-fired fluidized bed units. A gas flow of 142 m^3/Mg is also included to represent a few direct-fired dryers in this range.

6.2 REGULATORY ALTERNATIVES

The purpose of this section is to define various regulatory alternatives or possible courses of action EPA could take to abate AS particulate emissions from the dryer. Regulatory alternatives that were considered are listed as follows:

1. Standards of performance for AS particulate emissions based on add-on controls,
2. Design, equipment, work practice, or operational standards or combinations of these which reflect the best system of continuous emission reduction.
3. No regulation.

6.2.1 ADD-ON CONTROLS

In application to particulate collection from AS dryers, both the venturi scrubber and the fabric filter represent add-on controls that have the potential to reduce AS emissions by over 99.9 percent, and thus are able to achieve control levels of similar stringency. Based on test measurements and control technology documentation[1,2,3] both the venturi scrubber and the baghouse can potentially reduce the AS emissions to less than 0.150 kilograms per Mg of AS production.[4]

6.2.1.1 Venturi Scrubbers

Medium energy (25-33 centimeters pressure drop) venturi scrubbers with high liquid to gas ratios have demonstrated an ability to reduce AS dryer emissions by more than 99.9 percent (from 77 and 108 kg/Mg to 0.160 and 0.145 kg/Mg).

Due to the high collection efficiency achieved and the fact that it is compatible, and complimentary, to the processes involved, venturi scrubbing is considered the most attractive add-on control system.

6.2.1.2 Fabric Filters

The only operating baghouse in the AS industry demonstrated a level of emission control (an average particulate collection efficiency of 98.7 percent) which is seemingly less than the stringency level achieved by the venturi scrubber. However, the fabric filter baghouse should also be able to achieve AS collection efficiencies greater than 99 percent based on similar applications in other industries.[1,2,3]

6.2.2 DESIGN, EQUIPMENT, WORK PRACTICE, OR OPERATIONAL STANDARDS

Section 111(h) of the Clean Air Act establishes a presumption against design, equipment, work practice, and operational standards. For example, a standard based on a specific type of drying equipment without add-on controls or a standard limiting the dryer air flow rate cannot be promulgated unless a standard of performance is not feasible.

Performance standards for control of AS dryer particulate emissions have been determined as practical and feasible; therefore, design, equipment, work practice, and operational standards were not considered as a regulatory option.

The point should be noted that uncontrolled emissions from all known dryers are too great to comply with existing state regulations even at the lowest air flow rates. It is, therefore impractical to consider a standard solely on the process equipment type or to limit emissions by specifying the air flow.

6.2.3 NO REGULATION

The alternative of no additional regulation may be appropriate when the impact of the regulation, or the potential for emission in the future, is insignificant. Under the no-regulation option, emission levels would be set by existing SIP regulations; typically these are in the range of 0.71 kg/Mg to 1.3 kg/Mg of AS production. This option is characterized by the use of a low energy wet scrubber to meet the required emission limit, a reduction of about 97 to 98 percent.

6.3 SUMMARY

Two regulatory alternatives apply to each of the 13 model plant cases. Option I, the no-regulation alternative, serves as an example for existing or baseline control, typically about 97 to 98 percent.* Option II, that of add-on controls, is characterized by the use of the venturi scrubber or the fabric filter which represent a 99.9 percent level of control. The model plants are used as a basis for estimating the environmental, energy, and economic impacts associated with application of the alternative regulatory options. (These are presented in Chapters 7 and 8.)

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*Baseline control reflects the degree of emission reduction which can be achieved by the enforcement of a typical state regulation. Baseline control is a reference for comparison rather than an example of the "best system."

6.4 REFERENCES

1. EPA, AP-40, Air Pollution Engineering Manual, 2nd Edition, May 1973, pp. 111-132.
2. Information provided by McIlvaine, Company in a telephone conversation between M. McIlvaine and R. Zerbonia, PES, May 2, 1979.
3. Control Techniques for Particulate Air Pollutants, U.S. Environmental Protection Agency, PA-51, p. 118.
4. Data contained in EPA emission test reports at ammonium sulfate plants by Scott Environmental Technology, Clayton Environmental Consultants, and Jackson and Marks Company.

7. ENVIRONMENTAL IMPACT

This chapter presents an assessment of the alternative regulatory options discussed in Chapter 6. It addresses the air, water, solid waste, noise and energy impacts associated with these alternative regulatory options.

7.1 AIR POLLUTION IMPACT

The air pollution impact of the alternative regulatory options for the ammonium sulfate industry is the effect of applying Option II limits on new plants as compared with the operation of the same plants under Option I. The degree of emission control under Option I would be determined by state and local regulations for the control of particulate emissions. A typical state regulation limit is taken as a basis for comparison. Emissions allowed by state regulations for various process weight rates (production rates) are shown in Figure 3-5. The values selected as typical are shown in the figure and are listed in Table 3-10 for the operating range of the typical or model plants. The impact of applying Option II is presented both in terms of mass emission reduction and in terms of ambient concentration reduction in the following sections.

7.1.1 National Air Pollution Emission Impact

The general description of the AS industry in Chapters 3 and 8 included three principal sources, i.e., caprolactam plants, synthetic plants and coke oven by-product operations. The available evidence for industry growth projections resulted in the following conclusion: Coke oven operations have leveled off and that ammonia from any new ovens may well be recovered as anhydrous ammonia rather than ammonium sulfate.[1] New coke ovens are being added to replace older units rather than being added as new capacity, with the net result that the AS from this source is expected to decline in the future. It is unlikely that more than four plants will implement modification or reconstruction in the five years following 1980.

Similarly, the AS from synthetic plants is expected to level off because of the superiority of DAP as a nitrogen carrier and the large quantities of AS available from caprolactam production. This trend, plus the fact that only about 60 percent of the available capacity is presently being used, strongly indicates that no new synthetic plants will be built in the foreseeable future (see Table 3-2). Replacement of dryers which will be 25 years old in 1985 is considered in the impact analysis. Two plants currently operating with old dryers are expected to replace them by 1985. The total capacity of these two plants is 24.5 Mg/hr (27 tons/hr). Replacement of this capacity is simulated with two new 13.6 Mg/hr (15 tons/hr) plants.

Caprolactam production, on the other hand, is expected to increase in response to an increase in demand of 5 to 7 percent per year.

1977 caprolactam production was 394 Gegagrams (Gg) while industry capacity was (and is) 511 Gg. At 6.1 percent growth rate (the industry's rate of growth from 1971 to 1977), 1985 annual production would be 633 Gg, 122 more than current caprolactam capacity. Additional facilities capable of producing the shortfall would have to be constructed, and under existing technologies would yield an additional 400 Gg of AS.

Replacement of older dryers associated with caprolactam AS production is limited in consideration to those constructed before 1960 and, therefore, 25 years old by 1985. Only one dryer meets this age requirement. One model plant at 50 tons/hr capacity simulates the replacement.

Table 7-1 summarizes the impact of a 0.15 kg/Mg Option (0.3 lb/ton) on caprolactam and coke oven by-product and synthetic AS plants which otherwise would be controlled by existing state regulations.

Table 7-1. IMPACT SUMMARY OF 1985 PARTICULATE EMISSIONS FROM AMMONIUM SULFATE PLANTS

Mg/year (tons/year)

Plant Type	Emissions Under Existing State Standards	Option II 0.150 kg/Mg (0.30 lb/ton)	1985 Emission Reduction
Caprolactam By-Product			
1. Growth	284 (313)	60 (66)	224 (246)
2. Replacement	208 (228)	45 (48)	164 (179)
3. Subtotal	492 (540)	105 (114)	388 (425)
Synthetic			
1. Growth	0	0	0
2. Replacement	113 (124)	20 (22)	93 (102)
3. Subtotal	113 (124)	20 (22)	93 (102)
Coke Oven By-Product			
1. Growth	0	0	0
2. Replacement	65 (72)	6 (7)	58 (64)
3. Subtotal	65 (72)	6 (7)	58 (64)
TOTAL	670 (737)	131 (144)	539 (593)

These emission values were determined using the methodology referred to as TRC Model IV.[2]

The reduction of particulate matter emissions to 0.15 kg/Mg (0.30 lb/ton) may be effected by emission control using a venturi scrubber at a moderate pressure drop or a baghouse. The baghouse may be somewhat superior to the scrubber in the collection of fine particulate, but it cannot collect the residual caprolactam, a hydrocarbon, which is carried through the system and emitted from the dryer principally as a vapor. The scrubber can collect a substantial portion (88 percent) of this vapor along with the particulate collection, even though it is present in small concentrations (60 ppm). A very small part of the caprolactam is present in solid form and may be picked up with a baghouse.

The impact analysis for the collection of caprolactam emitted from the AS dryer is shown in Table 7-2. With a scrubber, the estimated caprolactam emission reduction is 464 Mg/year (510 tons/year) in addition to the 539 Mg/year (593 tons/year) of particulate matter. These results apply only to the add-on regulatory option. Clearly, the no-regulation option means no control beyond existing standards and, hence, no impact.

7.1.2 Dispersion Analysis and Models

A dispersion analysis for the model plants was performed to determine the maximum ground level concentrations of particulate matter (AS) (and caprolactam) around the principal AS plant types and to determine the locations of the maxima from the point of discharge. The analysis was carried out using the Industrial Sources Complex (ISC) Dispersion model and "worst case" climatological conditions. The ISC Model short-term computer program (ISCST) was used to compute the maximum 24-hour average particulate concentration and the maximum 3-hour and 24-hour average caprolactam concentration for distances beyond 100 meters from the plant. The

Table 7-2. IMPACT SUMMARY FOR 1985 CAPROLACTAM EMISSION FROM CAPROLACTAM AMMONIUM SULFATE PLANTS COINCIDENT WITH PARTICULATE EMISSION CONTROL

Mg/year (tons/year)

Control Type	Uncontrolled Emission	Emission with Control Device	Emission Reduction
Scrubber			
1. Industry Growth	312 (343)	44 (48)	268 (295)
2. Replacement	228 (250)	32 (35)	196 (215)
Total	540 (293)	76 (83)	464 (510)
Baghouse			
1. Industry Growth	312 (343)	295 (324)	17 (19)
2. Replacement	228 (250)	216 (238)	12 (13)
Total	540 (293)	511 (562)	29 (32)

3-hour maximum reflects the national ambient air quality standard specification for hydrocarbons. The ISC model long-term program (ISCLT) was used to compute the annual average concentrations of particulate and caprolactam again at distances beyond 100 meters. The impact data for the dispersion analysis were taken from the model plant description.

The Industrial Source Complex (ICS) Dispersion Model used in the dispersion analysis is an extension of existing EPA models to assess the air quality impact of emissions from a variety of sources associated with an industrial source complex. It also accounts for the effects of gravitational settling on ground-level concentrations and deposition.

The short-term model (ISCST) extends the EPA Single-Source Model (CRSTER). The long-term model (ISCLT) combines the basic features of the Air Quality Display Model (AQDM) and the Climatological Dispersion Model (CDM) to compute the annual ground-level concentration. A more detailed description of the model is available in Reference 3. The ISC model is estimated to be accurate to a factor of 2 based on tests of the parent models.

7.1.2.1 Model Plant Characteristics

AS plant stack and emission data based on the model plant parameters defined in Chapter 6 were used as the input data to the dispersion models. These parameters are summarized in Table 7-3. The process components and mass balance for typical caprolactam by-product AS plants are shown in Figure 3-2; for synthetic AS production, Figure 3-3; for coke oven by-product plants, Figure 3-4.

7.1.2.2 Meteorological Considerations

Meteorological data from four locations were used to determine the "worst case" dispersion conditions around the AS plants. Data from rural Mobile, Alabama, and Burrwood, Louisiana, were used for

Table 7-3. SOURCE DATA FOR DRYERS

	Data that Vary with Dryer Air Flow Rate				Data that Do Not Change with Dryer Air Flow Rate			
Plant Type	Air Flow Rate (dscm/kg)	Stack Diameter (m)	Particulate Emission Rate (g/sec)	Caprolactam Emission Rate (g/sec)	Stack Height (m)	Stack Exit Velocity (m/sec)	Stack Exit Temperature (°K)	Operating Hours
			(a) Baseline Control Option					
Primary	0.156	0.240	3.17	--	12.2	15.24	316	5400
	0.624	0.479	3.17	--				
	1.561	0.759	3.17	--				
	2.497	0.959	3.17	--				
Caprolactam	0.156	0.310	8.94	6.30	18.3	15.24	316	8400
	0.624	0.619	8.94	6.30				
	1.561	0.979	8.94	6.30				
	2.497	1.238	8.94	6.30				
	2.762	1.399	8.94					
Coke Oven	0.156	0.107	8.22×10^{-1}	--	6.1	15.24	316	7400
	0.624	0.215	8.22×10^{-1}	--				
	1.561	0.340	8.22×10^{-1}	--				
	2.497	0.429	8.22×10^{-1}	--				
			(b) Baghouse Option					
Primary	0.156	0.250	0.567	--	12.2	15.24	353	5400
	0.624	0.501	0.567	--				
	1.561	0.793	0.567	--				
	2.497	1.002	0.567	--				
Caprolactam	0.156	0.323	1.89	6.30	18.3	15.24	353	8400
	0.624	0.647	1.89	6.30				
	1.561	1.023	1.89	6.30				
	2.497	1.294	1.89	6.30				
	2.726	1.461	1.89	6.30				
Coke Oven	0.156	0.113	0.113	--	6.1	15.24	353	7400
	0.624	0.227	0.113	--				
	1.561	0.358	0.113	--				
	2.497	0.453	0.113	--				
			(c) Venturi Scrubber Option					
Primary	0.156	0.240	0.567	--	12.2	15.24	316	5400
	0.624	0.479	0.567	--				
	1.561	0.759	0.567	--				
	2.497	0.959	0.567	--				
Caprolactam	0.156	0.310	1.89	0.76	18.3	15.24	316	8400
	0.624	0.619	1.89	0.76				
	1.561	0.979	1.89	0.76				
	2.497	1.238	1.89	0.76				
	2.726	1.399	1.89	0.76				
Coke Oven	0.156	0.107	0.113	--	6.1	15.24	316	7400
	0.624	0.215	0.113	--				
	0.561	0.340	0.113	--				
	2.497	0.429	0.113	--				

caprolactam by-product AS plants; Tulsa, Oklahoma, and Columbia, Missouri, were used for the synthetic AS plants; and Pittsburgh, Pennsylvania, for coke oven AS plants, during the periods 1973 to 1975. The climate of these areas is similar to that of areas where new construction may be expected. From the record of sequential hourly data, 20 "worst case" days were selected for the 24-hour calculations for each plant type. The two caprolactam AS stacks were oriented North and South for maximum interaction.

Similarly, 3-hour "worst case" dispersion conditions were determined for the maximum 3-hour caprolactam concentrations. For the annual concentrations, the "STAR" summary was used which incorporated the frequency of wind speed and direction classified according to the Pasquill Stability Categories.

The location of the point of maximum ground-level concentration and the concentrations at various distances from the plant were determined using a radial receptor grid. Receptors were placed at 100, 1000, and 10,000 meters from the source with seven additional receptors interspersed between these points. Angular spacing of these points at 10° intervals provided receptors at 360 points around the source. A preliminary analysis indicated that the point of maximum ground-level concentration was located beyond 100 meters, the minimum model distance.

No terrain effects were included in the analysis except those implicitly contained in the meteorological data for the Mobile, Alabama, and Tulsa, Oklahoma, areas.

The ISC model calculations indicate that the meteorological conditions associated with the maximum short-term concentrations from ammonium sulfate plants occur infrequently. During only 6 days in 1964 did meteorological conditions prevail which would permit concentrations within 80 percent of the maximum values indicated. This frequency applies to the caprolactam plant, synthetic, and coke oven AS plants. The maximum short-term concentrations of both particulate and caprolactam emission for both plants is estimated to occur not more than 3 to 4 percent of the year.

7.1.2.3 Results and Discussion of the Dispersion Analysis

The results of the dispersion analysis under "worst case" meteorological conditions are presented in Tables 7-4 through 7-12. These values assume a pristine atmosphere and should be added to any background concentrations. Ambient AS concentrations are less for baghouse control than for venturi; this reflects the greater plume buoyancy due to the higher discharge temperature at the baghouse, i.e., 80°C (177°F) versus 43°C (110°F), even though the emission rate is identical with that of the scrubber discharge.

The national primary ambient air quality standards for particulate matter as published in the Federal Register, Volume 36 No. 84, April 30, 1971 are:

- 75 μgs/m^3, annual geometric mean
- 260 μgs/m^3 - maximum 24-hour concentration not to be exceeded more than once a year.

Caprolactam By-Product Plants

For the caprolactam by-product model plants, the maximum 24-hour average particulate ground-level concentrations occur at 700 meters. The maximum 24-hour concentration is reduced by a factor of 80 percent (224 to 47.4 $\mu g/m^3$) by controlling to 0.15 kg/Mg rather than the state emission limit. The maximum annual average occurs at 300 meters and is reduced by a factor of 80 percent (29.1 to 6.15 $\mu g/m^3$) by control with a venturi scrubber.

In those areas where the ambient standards are attained, the Option II model plant contributions appear to be satisfactory for installation in Class II and III areas but they would be too great to meet the 24-hour maximum increment requirement for a Class I area.

Table 7-4. MAXIMUM 24-HOUR AVERAGE PARTICULATE CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT CAPROLACTAM PLANTS FOR FIVE AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio				
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg	2.726 m^3/kg
(a) Baseline Control Option					
100	9.32×10^{1}	4.35×10^{1}	1.52×10^{1}	6.35	3.48
700*	2.24×10^{2}	1.46×10^{2}	8.94×10^{1}	7.01×10^{1}	6.22×10^{1}
1,000	1.03×10^{2}	8.71×10^{1}	7.05×10^{1}	5.93×10^{1}	5.21×10^{1}
10,000	6.19	6.18	4.71	4.70	4.69
(b) Baghouse Option					
100	1.39×10^{1}	3.00	5.49×10^{-1}	3.21×10^{-1}	2.43×10^{-1}
700*	4.23×10^{1}	2.36×10^{1}	1.25×10^{1}	9.28	7.83
1,000	2.11×10^{1}	1.63×10^{1}	1.18×10^{1}	8.39	7.08
10,000	1.31	9.98×10^{-1}	9.92×10^{-1}	9.87×10^{-1}	7.20×10^{-1}
(c) Venturi Scrubber Option					
100	1.97×10^{1}	9.19	3.22	1.34	7.36×10^{-1}
700*	4.74×10^{1}	3.08×10^{1}	1.89×10^{1}	1.48×10^{1}	1.31×10^{1}
1,000	2.19×10^{1}	1.84×10^{1}	1.49×10^{1}	1.25×10^{1}	1.10×10^{1}
10,000	1.31	1.31	9.96×10^{-1}	9.94×10^{-1}	9.91×10^{-1}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

Table 7-5. MAXIMUM 24-HOUR AVERAGE PARTICULATE CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT PRIMARY PRODUCTION PLANTS FOR FOUR AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio			
	$0.156\ m^3/kg$	$0.624\ m^3/kg$	$1.561\ m^3/kg$	$2.497\ m^3/kg$
	(a) Baseline Control Option			
100	1.02×10^{2}	6.82×10^{1}	3.98×10^{1}	2.56×10^{1}
300*	1.56×10^{2}	1.22×10^{2}	1.02×10^{2}	8.70×10^{1}
1,000	5.27×10^{1}	4.07×10^{1}	3.33×10^{1}	3.01×10^{1}
10,000	3.01	2.93	2.84	2.78
	(b) Baghouse Option			
100	1.39×10^{1}	5.46	1.36	8.66×10^{-1}
300*	2.58×10^{1}	1.93×10^{1}	1.35×10^{1}	1.03×10^{1}
1,000	7.74	5.89	5.06	4.44
10,000	5.26×10^{-1}	4.97×10^{-1}	4.67×10^{-1}	4.26×10^{-1}
	(c) Venturi Scrubber Option			
100	1.83×10^{1}	1.22×10^{1}	7.11	4.58
300*	2.79×10^{1}	2.20×10^{1}	1.82×10^{1}	1.56×10^{1}
1,000	9.43	7.29	5.96	5.39
10,000	5.39×10^{-1}	5.24×10^{-1}	5.08×10^{-1}	4.96×10^{-1}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, and 2.497, cubic meters per kilogram of ammonium sulfate production.

Table 7-6. MAXIMUM 24-HOUR AVERAGE PARTICULATE CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT COKE OVEN OPERATIONS FOR FOUR AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio			
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg
(a) Baseline Control Option				
100	2.33×10^2	1.42×10^2	7.73×10^1	4.90×10^1
200*	2.33×10^2	1.42×10^2	1.01×10^2	8.20×10^1
1,000	1.41×10^1	1.37×10^1	1.30×10^1	1.23×10^1
10,000	4.41×10^{-1}	4.41×10^{-1}	4.40×10^{-1}	4.37×10^{-1}
(b) Baghouse Option				
100	2.92×10^1	1.50×10^1	6.82	3.45
200*	2.92×10^1	1.60×10^1	1.10×10^1	7.74
1,000	1.92	1.84	1.68	1.53
10,000	6.06×10^{-2}	6.06×10^{-2}	6.04×10^{-2}	6.02×10^{-2}
(c) Venturi Scrubber Option				
100	3.20×10^1	1.95×10^1	1.06×10^1	6.73
200*	3.20×10^1	1.95×10^1	1.39×10^1	1.13×10^1
1,000	1.93	1.88	1.78	1.69
10,000	6.07×10^{-2}	6.06×10^{-2}	6.05×10^{-2}	6.04×10^{-2}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, and 2.497 cubic meters per kilogram of ammonium sulfate production.

Table 7-7. MAXIMUM ANNUAL AVERAGE PARTICULATE CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT CAPROLACTAM PLANTS FOR FIVE AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio				
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg	2.726 m^3/kg
	(a) Baseline Control Option				
100	4.47	1.30	2.73×10^{-1}	8.03×10^{-2}	4.89×10^{-2}
500*	2.91×10^{1}	1.84×10^{1}	1.21×10^{-1}	9.20	7.96
1,000	1.37×10^{1}	1.13×10^{1}	9.17	7.83	7.09
10,000	4.27×10^{-1}	4.42×10^{-1}	4.14×10^{-1}	4.08×10^{-1}	4.04×10
	(b) Baghouse Option				
100	6.08×10^{-1}	8.47×10^{-2}	1.52×10^{-2}	6.22×10^{-3}	3.64×10^{-3}
700*	5.65	3.18	1.85	1.35	1.10
1,000	2.82	2.14	1.56	1.26	1.08
10,000	9.01×10^{-2}	8.82×10^{-2}	8.52×10^{-2}	8.28×10^{-2}	8.12×10^{-2}
	(c) Venturi Scrubber Option				
100	9.45×10^{-1}	2.75×10^{-1}	5.78×10^{-2}	1.70×10^{-2}	1.04×10^{-2}
500*	6.15	3.88	2.56	1.95	1.68
1,000	2.90	2.40	1.94	1.66	1.50
10,000	9.02×10^{-2}	8.91×10^{-2}	8.75×10^{-2}	8.62×10^{-2}	8.52×10^{-2}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

Table 7-8. MAXIMUM ANNUAL AVERAGE PARTICULATE CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT PRIMARY PRODUCTION PLANTS FOR FOUR AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio			
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg
	(a) Baseline Control Option			
100	8.75	3.10	9.00×10^{-1}	3.58×10^{-1}
400*	2.45×10^{1}	1.71×10^{1}	1.10×10^{1}	8.51
1,000	8.51	6.78	5.61	4.94
10,000	3.94×10^{-1}	3.70×10^{-1}	3.46×10^{-1}	3.30×10^{-1}
	(b) Baghouse Option			
100	1.16	2.54×10^{-1}	4.52×10^{-2}	2.30×10^{-2}
400*	4.12	2.52	1.48	1.07
1,000	1.50	1.16	9.26×10^{-1}	7.86×10^{-1}
10,000	7.03×10^{-2}	6.47×10^{-2}	5.83×10^{-2}	5.48×10^{-2}
	(c) Venturi Scrubber Option			
100	1.57	5.55×10^{-1}	1.61×10^{-1}	6.41×10^{-2}
400*	4.39	3.06	1.98	1.52
1,000	1.53	1.21	1.00	8.81×10^{-1}
10,000	7.03×10^{-2}	6.60×10^{-2}	6.23×10^{-2}	5.90×10^{-2}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

Table 7-9. MAXIMUM ANNUAL AVERAGE PARTICULATE CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT COKE OVEN OPERATIONS FOR FOUR AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio			
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg
(a) Baseline Control Option				
100	2.35×10^{1}	1.41×10^{1}	7.85	5.09
200*	2.35×10^{1}	1.41×10^{1}	9.29	7.62
1,000	1.47	1.41	1.33	1.28
10,000	3.54×10^{-2}	3.53×10^{-2}	3.51×10^{-2}	3.51×10^{-2}
(b) Baghouse Option				
100	2.99	1.59	7.24×10^{-1}	3.90×10^{-1}
200*	2.99	1.59	1.09	8.23×10^{-1}
1,000	2.02×10^{-1}	1.93×10^{-1}	1.78×10^{-1}	1.67×10^{-1}
10,000	4.86×10^{-3}	4.85×10^{-3}	4.83×10^{-3}	4.80×10^{-3}
(c) Venturi Scrubber Option				
100	3.23	1.94	1.08	7.00×10^{-1}
200*	3.23	1.94	1.28	1.05
1,000	2.03×10^{-1}	1.94×10^{-1}	1.82×10^{-1}	1.76×10^{-1}
10,000	4.97×10^{-3}	4.85×10^{-2}	4.83×10^{-3}	4.82×10^{-3}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

Table 7-10. MAXIMUM 3-HOUR AVERAGE CAPROLACTAM CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT CAPROLACTAM PLANTS FOR FIVE AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio				
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg	2.726 m^3/kg
(a) Baseline Control Option					
100	3.33×10^2	1.54×10^2	6.06×10^1	2.70×10^1	1.53×10^1
300*	4.52×10^2	3.07×10^2	2.08×10^2	1.63×10^2	1.44×10^2
1,000	2.72×10^2	2.00×10^2	1.44×10^2	1.05×10^2	9.12×10^1
10,000	2.05×10^1	1.79×10^1	1.79×10^1	1.79×10^1	1.79×10^1
(b) Baghouse Option					
100	2.47×10^2	5.40×10^1	1.38×10^1	8.56	6.48
400*	3.77×10^2	2.17×10^2	1.27×10^2	8.91×10^1	7.18×10^1
1,000	2.49×10^2	1.58×10^2	8.83×10^1	5.89×10^1	5.11×10^1
10,000	2.05×10^1	1.79×10^1	1.79×10^1	1.24×10^1	8.91
(c) Venturi Scrubber Option					
100	3.99×10^1	1.85×10^1	0.73×10^1	3.24	1.84
200*	5.40×10^1	3.69×10^1	2.49×10^1	1.95×10^1	1.73×10^1
1,000	3.27×10^1	2.40×10^1	1.73×10^1	1.26×10^1	1.09×10^1
10,000	2.46	2.15	2.15	2.15	2.15

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

Table 7-11. MAXIMUM ANNUAL AVERAGE CAPROLACTAM CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT CAPROLACTAM PLANTS FOR FIVE AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio				
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg	2.726 m^3/kg
			(a) Baseline Control Option		
100	3.15	9.18×10^{-1}	1.93×10^{-1}	5.66×10^{-2}	3.45×10^{-2}
500*	2.05×10^{1}	1.29×10^{1}	8.52	6.48	5.61
1,000	9.68	8.00	6.46	5.52	5.00
10,000	3.01×10^{-1}	2.96×10^{-1}	2.92×10^{-1}	2.87×10^{-1}	2.84×10^{-1}
			(b) Baghouse Option		
100	2.02	2.82×10^{-1}	5.05×10^{-2}	2.07×10^{-2}	1.22×10^{-2}
700*	1.88×10^{1}	1.06×10^{1}	6.18	4.52	3.69
1,000	9.40	7.13	5.22	4.17	3.62
10,000	3.00×10^{-1}	2.94×10^{-1}	2.84×10^{-1}	2.76×10^{-1}	2.70×10^{-1}
			(c) Venturi Scrubber Option		
100	0.38	1.10×10^{-1}	2.30×10^{-1}	0.68×10^{-2}	0.4×10^{-2}
500*	2.46	1.55	1.02	0.78	0.68
1,000	1.16	0.96	0.78	0.66	0.60
10,000	0.36×10^{-1}	0.36×10^{-1}	0.35×10^{-1}	0.35×10^{-1}	0.34×10^{-1}

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

Table 7-12. MAXIMUM 24-HOUR AVERAGE CAPROLACTAM CONCENTRATIONS CALCULATED FOR AMMONIUM SULFATE DRYERS AT CAPROLACTAM PLANTS FOR FIVE AIR FLOW-TO-PRODUCTION RATIOS

(Micrograms Per Cubic Meter)

Distance (m)	Concentration by Air Flow-to-Production Ratio				
	0.156 m^3/kg	0.624 m^3/kg	1.561 m^3/kg	2.497 m^3/kg	2.726 m^3/kg
			(a) Baseline Control Option		
100	6.57×10^1	3.06×10^1	1.07×10^1	4.47	2.45
700*	1.58×10^2	1.03×10^2	6.30×10^1	4.94×10^1	4.38×10^1
1,000	7.29×10^1	6.14×10^1	4.97×10^1	4.18×10^1	3.67×10^1
10,000	4.36	4.35	3.32	3.31	3.30
			(b) Baghouse Option		
100	4.64×10^1	1.00×10^1	1.83	1.07	8.10×10^{-1}
700*	1.41×10^2	7.87×10^1	4.17×10^1	3.09×10^1	2.61×10^1
1,000	7.02×10^1	5.45×10^1	3.94×10^1	2.80×10^1	2.36×10^1
10,000	4.36	3.36	3.31	3.29	2.40
			(c) Venturi Scrubber Option		
100	7.89	3.69	1.29	0.54	0.29
300*	18.96	12.3	7.56	5.9	5.25
1,000	7.23	7.35	5.97	5.0	4.4
10,000	0.52	0.52	0.4	0.4	0.4

*Distances to the maximum concentrations calculated at or beyond 100 meters from the stack for air flow-to-production ratios of 0.156, 0.624, 1.561, 2.497, and 2.726 cubic meters per kilogram of ammonium sulfate production.

The maximum allowable increase in the 24-hour concentration as defined by 40 CFR 52.21 is 10 $\mu g/m^3$. This judgment assumes that the 45 Mg/hour plant is considered to be a major source.

The ground-level concentrations of caprolactam are shown in Tables 7-10, 7-11, and 7-12 which include the 3-hour maximum average as well as the 24-hour and annual averages. Only the maximum 3-hour concentration is specified as an ambient standard for hydrocarbons. Since caprolactam is a hydrocarbon, it would relate to the ambient standard of 160 $\mu g/m^3$ (0.24 ppm) maximum 3-hour concentration (6 to 9 a.m.), not to be exceeded more than once per year. Clearly, a 45 Mg/hr AS plant with a venturi scrubber that collects hydrocarbons as well as particulate would not exceed this value.

Synthetic Plant

The 24-hour and annual average particulate concentrations near a 13.6 Mg/hr synthetic plant are shown in Tables 7-5 and 7-8.

The results show that the 24-hour average particulate ground-level concentration would be reduced from 156 to 27.9 $\mu g/m^3$ with a venturi scrubber controlled to 0.15 kg/Mg (0.3 lb/ton). The baghouse is slightly more effective because it does not reduce the air temperature significantly and thus maintains the plume buoyancy. Again, the total emission is the same.

The controlled Option II concentrations could meet applicable standards when operating alone. In conjunction with other plants in an attainment locality, the contribution to the ambient particulate value could be important to area growth. In nonattainment areas, stringent control is necessary to minimize offset values and to allow for progress toward meeting the ambient standards.

Coke Oven Plant

The coke oven plant results shown in Tables 7-6 and 7-9 indicate lesser ambient air concentration impacts for the smaller plants.

7.2 WATER POLLUTION IMPACT

Effluent guidelines set forth in 40 CFR 418.60 limit water pollution from synthetic and coke oven AS plants but not caprolactam AS plants. It requires zero discharge of "effluent" to navigable waters. If a discharge should be made into a municipal sewer, it must be pretreated to reduce ammonia to 30 mg (as N) per liter. There are no limitations on biological oxygen demand (BOD), total suspended solids (TSS), or pH. The guidelines for caprolactam plants have yet to be written.

The caprolactam AS plant has a comparatively large throughput of water because the feed stock is a 40 percent solution of AS and water. The water evaporated in the crystallizer is condensed and recycled to the principal plant for plant use.

The synthetic AS plants achieve the zero discharge requirement readily since the water input to the plant (in the acid) is lost by evaporation from the crystallizer or the scrubber. Most of the water evaporated from the crystallizer is condensed and recycled to the scrubber and mother liquor tank systems. A small quantity of make-up water (1 gallon per minute in one case) is needed and none is discharged.

The coke oven plant may operate the scrubber system separately from the saturator condenser system. With continuous removal of scrubber water, a very small quantity of nitrogen may be lost in the discharge.

The necessity for adding a scrubber for emission control creates no water pollution problems and there is no impact. The same would be true for a baghouse application where the AS collected must be mixed with water for recycle to the process. The product AS is generally stored in warehouses which protect it from runoff with rainwater. One of the most beneficial impacts of scrubbers is that they return a valuable product (AS fines) to the process for recovery, and for this reason the scrubber may serve as an integral part of the process. With the baghouse, an extra step is necessary to reslurry the AS collected.

7.3 SOLID WASTE IMPACT

The AS plants generate no solid waste as part of the processes. The fines from the screening process are either sold as a product or recycled to the plant. The scrubber (or baghouse) catch is returned to the process. Any inert material input passes out with the product.

7.4 ENERGY IMPACT

The implementation of Option II for the AS plant would increase the energy requirements for scrubbers by a factor which depends on the level of emission control required. For the 45 Mg/hr caprolactam plant with two 2.49 m^3/kg (80,000 dscf/ton) dryers and two venturi scrubbers, the added pressure drop of 10 in. water column (13 in. with a venturi less 3 in. for an elementary scrubber) would increase the horsepower requirement for the two fan motors from 70 to 305 hp metric (69 to 301 hp engl.), an increase of 235 hp metric (232 hp engl.). The added horsepower needed to increase the ratio from 0.4 to 3.5 l/am^3 (3 to 26 $gal/10^3$ acf) would raise the horsepower requirement of the two pumps from 32.5 to 278 hp metric (32 to 274 hp engl.), an increase of 245 hp metric (242 hp engl.). The equivalent energy consumption would be 441 Kw-hr/hr, or about 0.65 percent of the total energy required to manufacture AS at caprolactam by-product AS plants.

The energy requirements for the synthetic AS plant will be lower in proportion to the lower air and water flow requirements per ton of product. Control to the same high-efficiency conditions as discussed with the caprolactam plant would require an increase of motor power from 8.2 to 48.6 hp (8.1 to 47.9 hp), an increase of 40.4 hp metric. The equivalent energy consumption would be 37 Kw-hr/hr, or less than

0.1 percent of the total energy required to manufacture AS at snythetic AS plants. Obviously, much or all of the added horsepower could be saved with the other regulatory options.

7.5 NOISE IMPACT

The implementation of Option II could theoretically increase the noise generated by the scrubber fan because of the higher pressure necessary for greater collection efficiency.[4] The increase in noise level can be limited by the installation of acoustical materials and overall design of the fan for low noise generation. One field observation of a fan operating at the high pressure level (13 in. W.C.) and in the open air, revealed no significant sound level above the background noise in the plant.

Occupational exposure to noise is regulated under Occupational Safety and Health Standards set forth in 29 CFR 1910.95.

7.6 REFERENCES

1. Chemical Engineering, March 19, 1976, p. 82.

2. Hopper, T.G. and W.A. Marrone, Impact of NSPS on 1985 National Emissions from Stationary Sources, Report Nos. EPA-450/3-017, TRC, Inc., May, 1976, p. 9-13.

3. Cramer, H.E. Company, Inc., Dispersion Model Analysis of the Air Quality Impact of Emissions from Ammonium Sulfate Production Plants, EPA Contract No. 68-02-2507.

4. Harris, C.M., Handbook of Noise Control, McGraw-Hill Book Company, 1957, pp. 25-10.

8.0 ECONOMIC IMPACT

Ammonium Sulfate (AS) is produced by 40 companies operating 61 plants in the U.S. Although a variety of production processes are utilized, three types of plants are predominant in the industry: (1) prime product, (2) coke oven by-product and (3) caprolactam by-product. In 1977 over 92 percent of total AS output was produced by plants using these three processes.

Approximately 95 percent of domestic consumption of AS is in the form of fertilizer. Other uses include tanning, food processing, water and sewage treatment, cattle food supplement and pharmaceuticals. None of these subsidiary uses takes up more than 2 percent of total AS production, and none of them is expected to increase in importance over the period 1979-1985. The agricultural sector is therefore likely to remain the dominant consumer of AS.

For geographical reasons, the U.S. is both an importer (from Canada) and an exporter (primarily to Latin America) of AS. Historically, exports have exceeded imports, although the size of exports has fallen since 1968 when AID subsidies for AS exports to third world countries were removed.

Capacity utilization in the industry is quite low (63 percent in 1978) and industry growth is expected to be minimal over the next seven years (1979-1985). At this time no company has specific plans to expand its capacity during that seven-year period although the possibility exists that one or two new caprolactam by-product plants will be constructed.

The economic impacts of implementation of Option II on the Ammonium Sulfate industry are likely to be negligible. Product prices will be virtually unaffected by the regulation. Rates of return on plant investments will decline by less than 1.05 percentage points for affected facilities earning relatively high rates of return on investment (15 percent) and by less than

0.68 percent for affected facilities earning relatively low rates of return (6 percent). Over the whole of the five-year period following promulgation, the estimated maximum total capital cost of the regulation for the AS industry is $0.958 million. This level of control expenditures appears to be affordable as it is less than 0.01 percent of the total value of current AS output. The estimated industry wide level of annualized costs of the standard in the fifth year following promulgation is relatively small, $0.480 million, also less than 0.01 percent of the total value of current AS output. Two factors account for the small impacts. First, the size of the control costs incurred by affected facilities in achieving the required emissions reductions are small relative to other costs. Second, two sector of the industry, synthetics and coke oven by-products, are likely to experience no growth over the five-year period (1980-1985) while growth in the third sector, caprolactam by-products, will be largely determined by economic conditions in the market for caprolactam, not the market for Ammonium Sulfate.

8.1. Industry Economic Profile

8.1.1. Product

8.1.1.1. Production

Ammonium Sulfate is a greyish white crystalline salt produced by the neutralization of ammonia with sulfuric acid. It is produced synthetically as a prime product, but larger quantities are manufactured as by-products in a variety of industrial processes. Such processes include the coking of coal, caprolactam manufacture, nickel reduction, acrylate and sulfuric acid production, and water and sewage treatment (see table 8-1).

Table 8-1. Production of Ammonium Sulfate by Source*
(10^3 Megagrams)

Year	Coke Oven By-product	Capro-lactam	Prime Product	Other	Total
1962	540	257	500	243	1540
1963	563	304	521	266	1654
1964	618	389	777	309	2093
1965	643	465	959	347	2414
1966	693	575	1048	288	2604
1967	670	582	1127	175	2556
1968	608	537	820	459	2424
1969	579	644	689	406	2317
1970	540	825	602	292	2259
1971	490	948	551	153	2142
1972	548	1019	505	161	2234
1973	544	1044	555	264	2408
1974	496	943	589	338	2366
1975	444	1012	606	292	2354
1976	450	1241	409	347	2447
1977	427	1102	456	164	2153
1978	407		(1709)**		2116

*Data by source not available for years prior to 1962.
**Includes caprolactam, prime product and other.

SOURCES: U.S. Department of Commerce, Bureau of the Census. Current Industrial Reports Series M28A, 1950-1975.

U.S. Dept. of the Interior, Bureau of Mines. Minerals Yearbook, 1950-1973.

Department of Energy Information Administration.

The three most important AS production processes are synthetic or prime product, coke oven by-product and caprolactam by-product. These processes are estimated to account for 23.5 percent, 12.1 percent and 47.4 percent of total U.S. ammonium sulfate capacity respectively. None of the remaining processes, nickel reduction, acrylate and sulfuric acid tail gas scrubbing, or water and sewage treatment, accounts for more than 4.6 percent of industry capacity. Each of the three major processes is discussed below.

(a) Synthetic Product. In synthetic AS plants ammonia is directly neutralized with sulfuric acid to produce ammonium sulfate. Typically these plants obtain feedstocks from other facilities although several are located in fertilizer complexes where products such as ammonia, ammonium nitrate, nitric acid, sulfuric acid and phosphoric acid are produced.[1] Average prime product plant capacity is estimated to be 79.01 Gg* (see table 8-3). Actual capacities range from 0.9 Gg to 263 Gg with six of the plants producing less than 60 Gg (see table 8-2).

Ten plants are currently in operation, all brought on stream prior to 1974. Seven of these are located in the West (California, Texas, Arizona and Idaho). The remaining three are in the East (New Jersey, Maine and Pennsylvania) (see figure 8-1). No new plants have been brought into full-time operation since 1973 and industry observers believe that no additional capacity will be constructed over the next seven years (1979-1985).[2] There is corroborating evidence for this view. David et. al.[3] examined the financial viability of six prime product plants in operation in 1973. Their study showed that if those plants had been required to bear the full costs of all

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*A gigagram (Gg) is equivalant to one million kilograms or one thousand metric tons.

Table 8-2. Ammonium Sulfate Producing Plants, Locations and Capacities

Company	Location	Capacity (10^3 Megagrams)
Prime Product		
Delta Chemicals, Inc.	Searsport, Me.	25.4
Heico, Inc.	Delaware Water Gap, Pa.	18.1
Occidental Petroleum Corp.		
Hooker Chemical Corp., subsidiary	Houston, Tx.	136.1
	Lathrop, Ca.	101.6
	Plainview, Tx.	136.1
Richardson-Merrell, Inc.		
J. T. Baker Co., subsidiary	Phillipsburg, N.J.	0.9
J. R. Simplot Co.		
Minerals & Chemical Div.	Pocatello, Idaho	40.8
Standard Oil Co. of California		
Chevron Chemical Co., subsidiary	Richmond, Ca.	59.0
Valley Nitrogen Producers, Inc.	Helm, Ca.	263.0
Arizona Agrochemical Co., subsidiary	Chandler, Az.	9.1
Caprolactam By-Product		
Allied Chemical Corp., Fibers Div.	Hopewell, Va.	838.3
Badische Corp.	Freeport, Tx.	400.0
Nipro, Inc.	Augusta, Ga.	354.7
Coke Oven By-Product		
Alabama By-Product Corp.	Tarrant, Ala.	10.9
Armco Steel Corp.	Hamilton, Ohio	7.3
	Houston, Tx.	3.6
Bethelehem Steel Corp.	Bethlehem, Pa.	24.5
	Burns Harbor, In.	20.9
	Johnstown, Pa.	21.8
	Lackawanna, N.Y.	39.0
	Sparrows Point, Md.	36.3
CF&I Steel Corp.	Pueblo, Colo.	(N.A.)
Chattanooga Coke and Chemicals Co.	Chattanooga, Tn.	(N.A.)
Colt Industries, Inc.		
Crucible Stainless Steel & Alloy Divison	Midland, Pa.	3.6
Donner-Hanna Coke Corp.	Buffalo, N. Y.	12.7
Empire Coke Co.	Tuscaloosa, Ala.	1.8
Inland Steel Co.	Indiana Harbor, In.	22.7
Interlake, Inc.	South Chicago, Ill.	3.6
Jones & Laughlin Industries, Inc.		
Jones & Laughlin Steel Corp., subsidiary	Aliquippa, Pa.	20.0
	Pittsburgh, Pa.	22.7
Kaiser Steel Corp.	Fontana, Ca.	23.6
Lykes Corp.		
Youngstown Sheet & Tube Co. Subsidiary	Campbell, Ohio	10.0
National Steel Corp.		
Granite City Steel Div.	Granite City, Ill.	5.4
Great Lakes Steel Div.	Zug Island, Mich.	(N.A.)
Weirton Steel Div.	Weirton, W. Va.	10.0
Northwest Industries, Inc.		
Lone Star Steel Co., subsidiary.	Lone Star, Tx.	3.6

Table 8-2 (continued)

Company	Location	Capacity (10^3 Megagrams)
Republic Steel Corp.		
Iron and Chemical Div.	Chicago, Ill.	4.5
	Cleveland, Oh.	24.5
	Gadsden, Ala.	10.0
	Massillon, Oh.	2.7
	Thomas, Ala.	3.6
	Warren, Oh.	4.5
	Youngstown, Oh.	11.8
Sharon Steel Corp.		
Fairmont Coke Works	Fairmont, W. Va.	5.4
Shenango, Inc.	Neville Island, Pa.	5.4
U.S. Steel Corp. USS Chemicals Div.		
	Fairfield, Ala.	(N.A.)
	Fairless Hills, Pa.	11.8
	Geneva, Utah	21.8
	Lorain, Ohio	20.0
Jim Walter Corp.		
Jim Walter Resources, Inc. subsidiary, Chemicals Div.	Birmingham, Ala.	14.5
Wheeling-Pittsburgh Steel Corp.	Follansbee, W. Va.	21.8
	Monessen, Pa.	8.2
Nickel Reduction		
AMAX Inc.		
AMAX Nickel Refining Co., Subs.	Braithwaite, La.	90.7
S.E.C. Corp.	El Paso, Tx.	2.4
Sulfuric Acid Tail Gas Scrubbing By-Product		
CF Industries, Inc.	Plant City, Fla.	21.8
Farmland Industries, Inc.	Green Bay, Fla.	14.5
Other		
Mallinckrodt, Inc.	Raleigh, N.C.	(N.A.)
Rohm and Haas Co.		
Rohm & Haas Texas Inc., subsidiary	Deer Park, Tx.	155.0
Tahoe Truckee Sanitation Agency	Truckee, Ca.	1.6
Upper Occoquan Sewage Authority (open May 1979)	Fairfax County, Va.	1.8

N.A. = not available

SOURCES:

Stanford Research International. 1978 Directory of Chemical Producers, pp. 457-458.

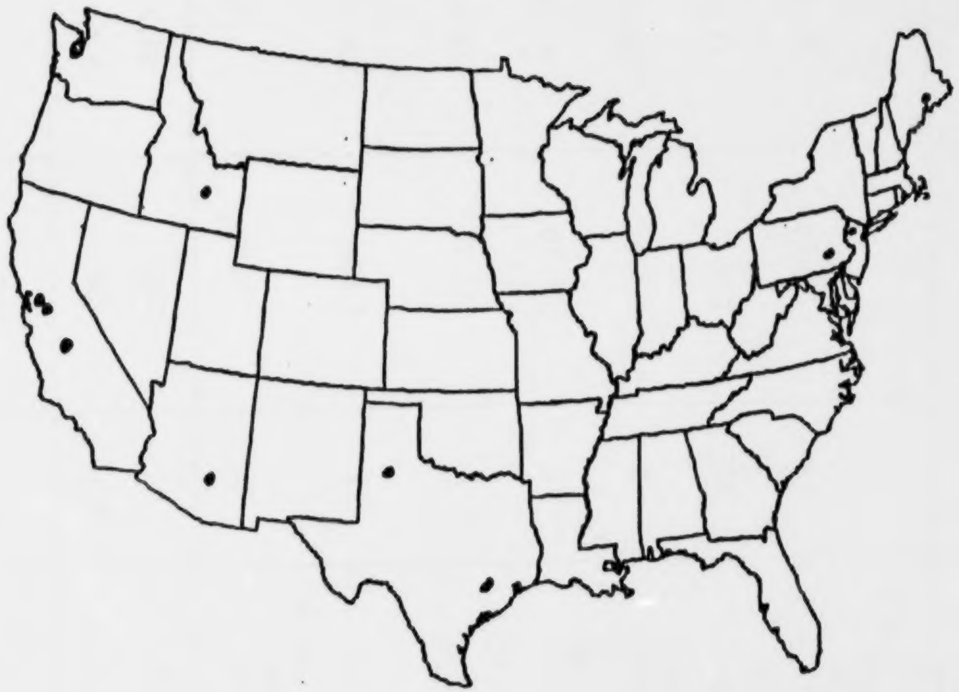
Research Triangle Institute.

Table 8-3. Ammonium Sulfate Capacity Distribution by Process - 1978

Process	Number of Plants	Total Plant Capacity (10^3 Megagrams)	Average Plant Capacity (10^3 Megagrams)	Share of Industry Capacity (%)
Synthetic Ammonium Sulfate	10	790.11	79.01	23.5%
Coke oven by-product	40	529.00	13.23	15.7%
Caprolactam by-product	3	1593.00	531.00	47.4%
Nickel Reduction by-product	2	93.10	46.55	2.8%
Sulfuric Acid Tail Gas by-product	2	36.30	18.15	1.1%
Acrylate by-product	1	155.00	155.00	4.6%
Water & sewage treatment by-product	2	3.40	1.70	.1%
SUBTOTAL	60	3200	53.3	95.2%
Other	N.A.	161	N.A.	4.8%
TOTAL	60+	3361	N.A.	100%

SOURCE: Table 8-2.

Figure 8-1. Ammonium Sulfate Synthetic Production Plants

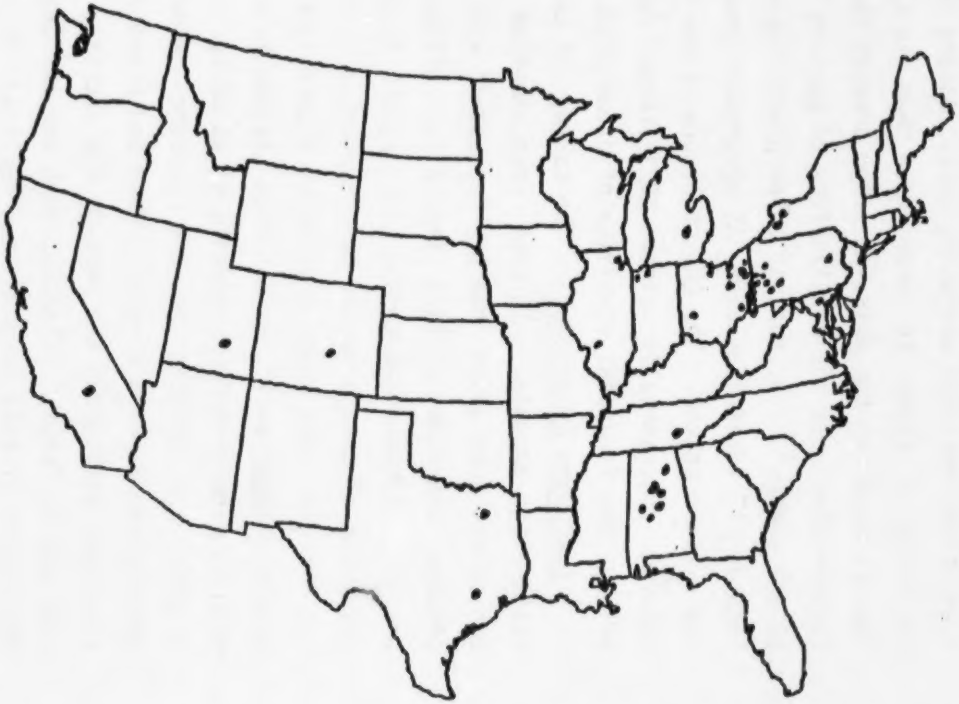


resources used in the production of AS, five of the plants would have experienced economic losses in that year, indicating that it would be unprofitable for companies to construct new AS facilities. However, all six plants were able to generate revenues to cover their variable operating costs, making it more advantageous for existing plants to stay open than to close down. Other factors enabling the existing prime product facilities to remain in operation were the availability of captive feedstocks on site at all plants[4], and, for the three plants located in California, locational advantages over AS by-product producers situated in the eastern states. As the structure of the AS industry has not altered substantially since 1973, these factors continue to protect the financial viability of prime producers.

Coke Oven By-product. The coking of coal generates gases containing ammonia. In coke oven ammonium sulfate by-product operations such gases can be "scrubbed" with sulfuric acid to produce ammonium sulfate crystals. Utilizing this type of process, between 7.5 kg and 13.5 kg of AS may be obtained for every ton of coke produced by the plant.

The 40 coke oven by-product plants currently in operation are relatively small, (plant size ranges from 1.8 Gg to 39 Gg), with an average annual capacity of 13.23 Gg. Twenty-four of the plants are located in the Eastern steel-producing states (Pennsylvania, West Virginia, Ohio and Alabama). The others are scattered throughout the rest of the country, with small concentrations in Texas, Illinois, Utah and Indiana (see figure 8-2). Production of coke oven AS has declined in recent years as has the number of plants utilizing this process. Coke oven by-product output peaked in 1966 when 693 Gg of AS were produced by 48 plants.[5,6] By 1973 the level of output had dropped to 544 Gg and the number of plants to 46.[7] In 1978, output from coke oven by-product plants declined still further to 407 Gg and the

Figure 8-2. Coke Oven By-product AS Plants



number of plants to 40. Further contraction of capacity is scheduled in the future. The U.S. Steel plant at Duluth will close in May, 1979.[8]

The decrease in coke oven AS production is the result of a shift on the part of coke oven by-product plants to the manufacture of alternative ammonia-based products such as ammonia liquor, diammonium phosphate and anhydrous ammonia. Quantitative data on the extent of such adjustments over the past five years is available for only one of these products, ammonia liquor. Between 1973 and 1978, coke oven by-product output of ammonia liquor almost tripled, from 5.6 Gg to 15.4 Gg.[9,10] Qualitative evidence indicating that shifts from the production of AS to the production of anhydrous ammonia are taking place was provided by industry sources.[11,12] This trend has been encouraged by the post-1973 increase in the price of anhydrous ammonia relative to the price of ammonium sulfate* and by the potential for spot-shortages in the supply of ammonia produced from natural gas.

Two factors suggest that the process of transition from AS production to other ammonia by-products will continue. First, many of the existing coke oven by-product plants are relatively old and may be due for reconstruction or replacement in the next five to ten years. In a survey of coke oven plants, David et. al. discovered that 20 of the 22 coke oven AS by-product plants whose ages could be determined were constructed before 1960.[13] Second, new technologies are being adopted which enable coke oven by-product facilities to produce more valuable high-quality anhydrous ammonia,* making that process a more profitable alternative.

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*In 1973 the ratio of the price of anhydrous ammonia to the price of AS was 1.59; over the period 1974-76 this ratio averaged 1.70.

The above factors suggest that the coke oven by-product sector of the AS industry is likely to contract over the period 1979-1985, although the rate of contraction is difficult to forecast.

Caprolactam By-product. Caprolactam can be produced by a number of processes, though only three are currently utilized in the U.S. Each of these processes involves the reaction of hydroxylaminesulfate with cyclohexanone to produce cyclohexanone sulfate. This compound is then neutralized with ammonia to produce caprolactam and AS. AS is also produced in the course of manufacturing the hydroxylaminesulfate, a process which is carried out on site. Slight variations in the processes used by BASF, Nipro and Allied Chemicals result in variations in the yield of AS per kg of caprolactam produced. The actual range of yields is estimated to be between 1.8 and 4.4 kg of AS per kg of caprolactam produced.[15] The three plants are located in Texas, Virginia and Georgia (see figure 8-3).

Although the caprolactam by-product sector of the AS industry consists of only three firms, their joint capacity is estimated to be 1593 Gg or 47.4 percent of total industry capacity, more than double that of any other sector of the

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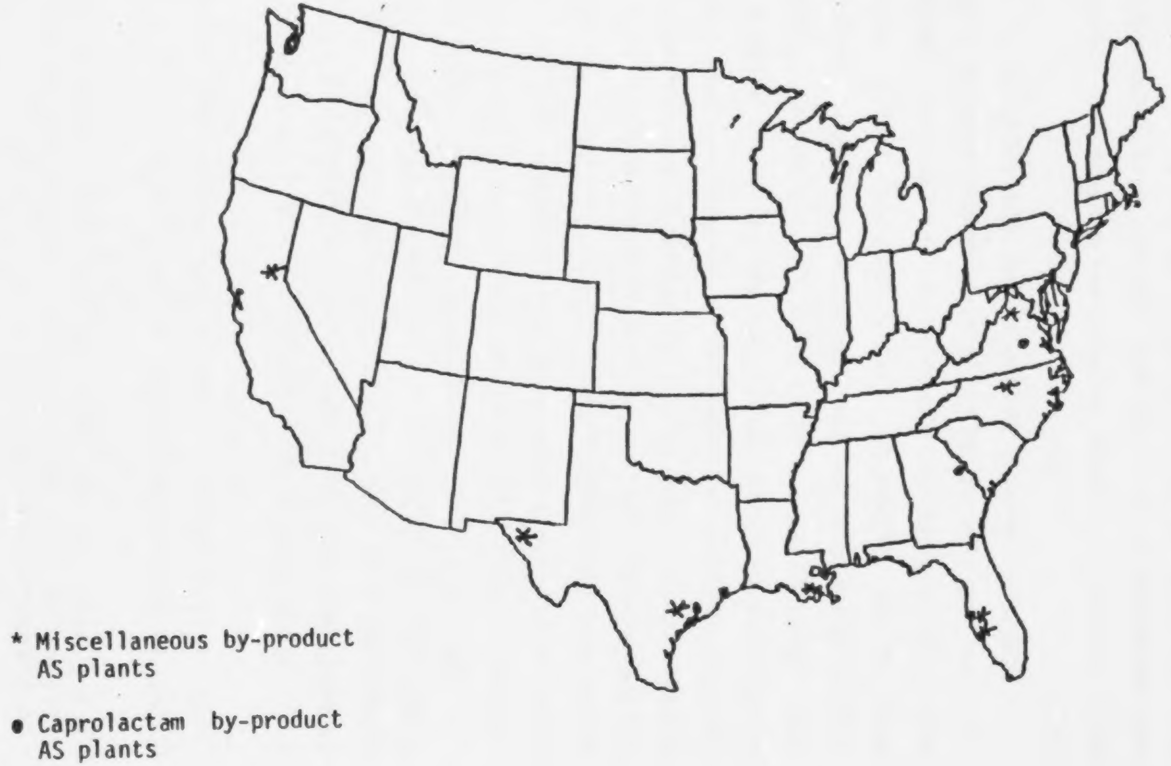
*One such technique is Phosam, developed by U.S. Steel and recently implemented by Armco Steel Corporation at its facility in Middletown, Ohio.[14]

Figure 8-3. Ammonium Sulfate Production Plants


* Miscellaneous by-product AS plants
● Caprolactam by-product AS plants

industry. In addition, 1977 caprolactam AS production was 1102 Gg, over 51 percent of total industry output for that year.* The caprolactam by-product sector achieved its dominant position in the domestic industry over the ten year period 1962-1972. In 1962, total caprolactam production was 257 Gg representing only 16.7 percent of total AS output. By 1972, however, sector output had increased to 1019 Gg, and its share of total output rose to 45.6 percent. Slower growth was experienced between 1972 and 1978.

Industry sources estimate that the caprolactam sector will continue to grow at an estimated annual rate of 5 to 7 percent[17] with a corresponding increase in its share of industry output. Much of the growth is likely to come at the expense of the declining sectors of the industry, synthetic product and coke oven by-product, as the industry-wide annual growth rate is expected to be quite small (between 1 and 2 percent). Despite the projections of substantial growth in the caprolactam by-product sector, none of the three companies currently manufacturing caprolactam intends to increase the size of its plants over the period 1979-1985.[18,19,20] In fact, Allied and Badische Corp. have indefinitely postponed or abandoned earlier proposals to increase the size of existing plants and/or construct facilities.**

The basis for the decision to delay construction of new plants may be the existence of excess capacity. In 1977, the production of caprolactam itself was 394 Gg[21] while industry capacity was 511 Gg[22], implying a relatively low sector capacity utilization rate of 77.1 percent. It should be noted, however, that if industry caprolactam production continues to increase at an annual rate of 6.1 percent between 1978 and 1985 (its rate of growth from 1971-1977), 1985 annual production of caprolactam would be 633 Gg, 122 Gg more than the current capacity. Additional facilities capable of producing the shortfall would have to be constructed and under existing technologies would yield an additional 400 Gg of AS. A slightly larger growth rate of 7 percent would result in a 1985 production level of 677 Gg of caprolactam, 166 Gg in excess of current output.

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*Data on 1978 caprolactam AS production has been withheld by the Bureau of Census for reasons of confidentiality.[16]

**C & E News., p. 12, June 18, 1979 reports that Dow-Badische Corporation will expand caprolactam capacity 20 percent at Freeport, Texas plant.

8.1.1.2. Resource Use

Estimates of labor and energy consumption in the three major sectors of the AS industry for 1976 are presented in table 8-4. Similar resource-use levels are presumed to have prevailed in 1977.

8.1.1.3. Product Use.

The primary use of AS is as a fertilizer. It is also employed in a number of industrial processes:

Fertilizer Use. Approximately 95 percent of apparent U.S. consumption of AS is in the form of fertilizer (see table 8-5). It is used because it provides two plant nutrients, nitrogen (N) and sulfur (S), which are lost in the process of continuous cropping. The product has two other desirable properties. First, AS crystals do not readily absorb water from the air, enabling the product to maintain its quality during transport and long periods of on-farm storage. Second, AS is particularly appropriate for use on high alkaline soils since an acid residue is formed as the fertilizer decomposes, neutralizing the excess alkaline. AS may be applied to crops directly or as part of a fertilizer blend which includes other macronutrients. The data presented in table 8-5 indicate that blend fertilizer applications have been and continue to be more important than direct applications.

Table 8-4. Resource Use, 1976

Resource	Industry Sector		
	Synthetic	Coke Oven By-product	Caprolactam By-product
Number of Workers	163	458	1005
Energy (10^{12}Btu's)	4.164	1.460	6.37

SOURCE: RTI (See Appendix A)

Table 8-5. Consumption of Ammonium Sulfate by Use
(10^3 Mg)

Year	Direct Application Fertilizer*	Fertilizer Mixtures+	Industrial Uses++	Total Apparent Consumption
1960	533	702-748	54-100	1335
1965	771	682-728	54-100	1553
1970	776	1158-1204	54-100	2034
1975	814	1122-1168	54-100	2036
1978	816	1091-1137	54-100	2007

*United States Department of Agriculture, Statistical Reporting Service, Crop Reporting Board. Consumption of Commercial Fertilizers in the U.S. Annual, 1960-1978.

+RTI estimates resultant from the subtraction of direct application fertilizer and industrial uses from total apparent consumption.

++Stanford Research Institute. Chemical Economics Handbook. 1976. Estimates in range due to fluctuations in consumption for industrial purposes.

Although U.S. fertilizer consumption of AS has increased between 1955 and 1978, the importance of AS as a nitrogen fertilizer has diminished. Until 1947, AS was the primary source of solid nitrogen fertilizer in the U.S. However, because of its relatively low nitrogen content (20.9 percent N) and its lack of other macronutrients (phosphate and potash), AS has been replaced by high analysis fertilizers as the major nitrogen source (see section 8.1.3). These fertilizers include ammonium nitrate (33.5 percent N), urea (45.5 percent N), anhydrous ammonia (82 percent N) and a variety of nitrogen solutions. The use of the high analysis fertilizers instead of AS is partly explained by their technological characteristics. (Urea, for example, is a quick release fertilizer, suitable for application just prior to harvesting, whereas AS is a slow release fertilizer, more usefully applied at planting.) In addition, the price per unit of nitrogen contained in AS is higher than the price per unit of nitrogen for the high analysis products.[*] Finally, shipping costs per unit of nitrogen from the plant to the farm gate are lower for the high analysis chemicals.

AS is also in demand because of its relatively high sulfur content (24 percent S). However, it is not the only fertilizer capable of providing sulfur to sulfur-depleted soils. Substitute chemicals include the superphosphates (1.2 percent to 11.9 percent S), potassium sulfate (18 percent S), elemental sulfur (30 to 99.6 percent S), and gypsum (16.8 percent S). In addition, new products such as sulfur-coated urea have become sulfur-substitutes for AS. Consequently, though the demand for

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[*] The price per kg of nitrogen for the major nitrogenous fertilizers in 1978 was as follows: AS, 57.5 cents; anhydrous ammonia, 18.6 cents; ammonium nitrate, 45.5 cents; Urea, 41.1 cents (see table 8-7).[23]

Table 8-6. United States Ammonium Sulfate and Nitrogen Consumption 1955-1978 (10^3 Megagram)

Year	Ammonium Sulfate Consumed	Nitrogen Available from Ammonium Sulfate	Total Nitrogen Consumed as Fertilizer	Ammonium Sulfate's Share of Total Nitrogen Consumed as Fertilizer
1955	1495	314	1779	17.65
1956	1314	285	1754	16.25
1957	1305	274	1937	14.15
1958	1324	278	2072	13.42
1959	1398	294	2423	12.13
1960	1335	280	2484	11.27
1961	1411	296	2750	10.77
1962	1368	287	3057	9.39
1963	1438	301	3564	8.45
1964	1706	358	3949	9.07
1965	1553	326	4208	7.75
1966	1452	305	4832	6.31
1967	1647	346	5468	4.47
1968	1310	275	6158	4.47
1969	1504	316	6312	5.00
1970	2034	427	6767	6.31
1971	2267	479	7379	6.45
1972	1897	398	7278	5.47
1973	2250	472	7525	6.28
1974	1846	388	8308	4.67
1975	2036	428	7809	5.47
1976	1897	398	9385	4.24
1977	2063	433	9659	4.48
1978	2007	421	9048	4.65

SOURCES: United States Dept. of Agriculture, Economic Research Service, *The Changing U.S. Fertilizer Industry*. Agricultural Economics Report No. 378. August 1977, p. 48, table 1.

United States Dept. of Agriculture, Economics, Statistics and Cooperatives Service. *Commercial Fertilizer: Consumption for Year Ended June 30, 1978.* November 1978, p. 6, table 2.

United States Dept. of Agriculture, Statistical Reporting Service, Crop Reporting Board. *Consumption of Commercial Fertilizer in the U. S., Annual*, 1956-1978.

Table 8-7. Fertilizer Prices
(Dollars per megagram)

Year	Ammonium Sulfate	Ammonium Nitrate	Urea	Anhydrous Ammonia	28% N Solution	Superphosphate
1955	49.52	97.11	N.A.	181.33	N.A.	38.64
1956	40.47	91.88	N.A.	173.61	N.A.	38.80
1957	36.55	89.07	N.A.	167.00	N.A.	39.41
1958	36.51	91.33	141.09	164.79	N.A.	40.95
1959	36.51	90.00	134.48	159.83	N.A.	41.28
1960	63.82	89.56	128.97	154.87	N.A.	41.61
1961	64.15	90.50	124.56	153.77	N.A.	42.16
1962	62.83	89.73	119.60	148.26	N.A.	42.33
1963	57.54	88.62	116.84	140.54	N.A.	44.42
1964	57.98	87.30	115.74	136.69	N.A.	44.31
1965	58.86	86.53	114.09	133.38	N.A.	44.92
1966	58.20	83.50	110.78	129.52	N.A.	45.52
1967	59.74	81.61	109.34	124.74	N.A.	46.41
1968	59.41	68.01	101.31	100.33	60.19	47.56
1969	57.87	67.95	92.28	83.16	45.44	48.67
1970	57.76	66.10	91.28	82.25	50.62	50.87
1971	56.99	69.80	90.28	87.68	55.25	53.35
1972	57.43	71.27	89.78	88.58	57.10	55.72
1973	60.85	78.66	99.31	96.72	63.27	60.46
1974	121.25	153.25	201.62	201.57	126.85	107.69
1975	163.14	204.95	268.83	291.96	168.65	121.80
1976	110.88	148.82	183.07	209.70	120.06	107.09
1977	115.40	158.42	185.08	200.21	125.16	111.94
1978	122.80	152.33	186.83	184.39	119.45	104.00

SOURCES:

United States Department of Agriculture, Economics, Statistics and Cooperatives Service. Agriculture Prices Annual Summary, 1960-1977.

United States Department of Agriculture, Economics, Statistics & Cooperatives Service, 1979 Fertilizer Situation, p. 10, table 5.

United States Department of Agriculture, Economic Research Service, The Changing U.S. Fertilizer Industry. Agricultural Economics Report No. 378. August 1977, p. 53, table 7.

sulfur fertilizers is likely to increase this does not necessarily imply that there will be a substantial strengthening in the demand for AS in the future.*

Industrial Use. Relatively small quantities of AS (approximately 5 percent of domestic consumption) are used in the manufacture of industrial products. These include cattle feed supplement, viscous rayon, fire control, fermentation, water and sewage treatment, pharmeceuticals, tanning, antibiotics and photographic equipment. Total industrial use of AS is estimated to be between 54 Gg and 100 Gg, and is not expected to increase substantially.[25]

8.1.2. Production Trends

Over the period 1955-1978 AS output levels have exhibited considerable variability, ranging from a low of 1354 Gg in 1960 to a high of 2604 Gg in 1966 (see table 8-8). In addition, no clear long term industry-wide production trend has been established. For example, in 1955 output was 1954 Gg and by 1978 it had only increased to 2116 Gg.

The period 1955-1978 can be divided into four phases: 1955-1960, 1961-1966, 1967-1971 and 1972-1978. In the first phase (1955-1960) AS production fell as domestic consumption remained static and export levels fell. Although general fertilizer use was increasing, farmers began to adopt high analysis fertilizers as a nitrogen source instead of increasing their use of AS.

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*The advent of pollution control has reduced sulfur dioxide emissions. Consequently, less sulfur is now being transmitted to the earth via rainfall than was the case prior to 1970. In addition, the switch to high analysis nitrogenous fertilizers has reduced the stock of sulfur in the soils. These two factors have combined to create the possibility of future depletion of sulfur in soils.[24]

Table 8-8. Ammonium Sulfate
Capacity, Production, Consumption and Inventories
(10^3 Megagrams)

Year	Capacity	Production	Percent Utilization	Consumption	Inventories
1955	N.A.	1954	N.A.	1495	N.A.
1956	N.A.	1795	N.A.	1314	N.A.
1957	N.A.	1770	N.A.	1305	N.A.
1958	N.A.	1570	N.A.	1324	N.A.
1959	N.A.	1555	N.A.	1398	N.A.
1960	N.A.	1354	N.A.	1335	N.A.
1961	1335	1402	105	1411	N.A.
1962	1411	1540	109	1368	N.A.
1963	1483	1654	112	1438	N.A.
1964	1703	2093	123	1706	N.A.
1965	2435	2414	99	1553	484
1966	2780	2604	94	1452	319
1967	2789	2556	92	1647	430
1968	2837	2424	85	1310	397
1969	2957	2317	78	1504	599
1970	2955	2259	76	2034	546
1971	2957	2142	72	2267	161
1972	2971	2234	75	1897	238
1973	3311	2408	73	2250	131
1974	3301	2366	72	1846	404
1975	3435	2354	68	2036	360
1976	3435	2447	58	1897	203
1977	3361	2153	57	2063	258
1978*	3361	2116	52	2007	325

*1978 Production data is based on the calendar year.

SOURCES:

British Sulphur Corp. London, England.

U.S. Dept. of Agriculture, Statistical Reporting Service, Crop Reporting Board. Consumption of Commercial Fertilizer in the U.S., 1956-1978.

U.S. Department of Commerce, Bureau of the Census. Current Industrial Reports Series M28B, 1966-1978.

U.S. Department of Commerce, Bureau of the Census. Current Industrial Reports Series M28A, 1965.

U.S. Dept. of Agriculture, Economics, Statistics, and Cooperatives Service. 1979 Fertilizer Situation, p. 9, table 3.

During the second phase (1961-1966) production went through a period of expansion, rising from 1402 Gg in 1961 to 2604 Gg in 1966.[*] The increase in production during this time can be explained by three factors: (1) the world-wide surge in the demand for nitrogenous fertilizer,[**] (2) the introduction of a U. S. A.I.D. program to subsidize AS exports to third world countries, particularly Latin America, and (3) the employment of new chemical processes capable of generating AS as a low cost by-product.

Following the peak output levels achieved in 1966, AS production began to wane despite record export levels demand in 1967. Output continued to fall during the third phase (1967-1971) until 1971, when production bottomed out at 2142 Gg. This period of declining output was partially the result of (1) excess capacity throughout the fertilizer industry and (2) a substantial decrease in demand for U.S. exports from 1461 Gg in 1966 to 468 Gg in 1971 (see table 8-9). The decline in foreign demand was associated with the termination of the U.S. AID subsidy program in 1968 and an increase in Latin American nitrogenous fertilizer capacity.

During the fourth phase (1972-1978), AS production fluctuated from year to year, exhibiting no apparent trend. This variability may partially be explained by divergent trends in separate sectors of the AS industry. In 1972 and 1973 a gradual contraction in coke oven by-product production was more than offset by expansion within the caprolactam sector. In 1974, however, caprolactam production was curtailed by rapidly

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[*] Four prime product plants were opened between 1960-1965.[26]

[**] The domestic price per metric ton of AS rose from $36.55 in 1959 to $63.82 in 1960 and remained at or close to that level between 1960 and 1965.

Table 8-9. Ammonium Sulfate Imports and Exports
(10^3 Megagrams)

Year	Imports	Exports	Net Exports
1955	157	555	398
1956	180	692	512
1957	150	709	559
1958	170	351	181
1959	197	363	166
1960	191	215	24
1961	224	131	-93
1962	219	489	270
1963	213	445	232
1964	160	439	279
1965	164	872	708
1966	145	1,461	1,316
1967	152	950	798
1968	119	1,266	1,147
1969	125	737	612
1970	198	474	276
1971	208	468	260
1972	239	471	232
1973	271	441	170
1974	234	505	271
1975	199	572	373
1976	513	682	169
1977	297	445	148
1978	295	355	60

SOURCES

U.S. Dept. of Commerce, Bureau of Economic Analysis. Business Statistics, March 1978, p. 123.

United States Department of Agriculture, Agricultural Stabilization and Conservation Service. The Fertilizer Supply 1973-74, 1973-74, 1974-75.

United States Department of Agriculture, Economics, Statistics and Cooperatives Service. 1979 Fertilizer Situation, December 1978, p. 18, tables 19 and 21.

U.S. Dept. of Commerce, Bureau of the Census. U.S. Exports Schedule B Commodity and Country Report FT - 410, 1955-1972.

increasing energy prices. The result was a reduction in the output of by-product ammonium sulfate and a decline in total AS production.

Output levels remained relatively unchanged in 1975 and increased only slightly in 1976. During these years, increased caprolactam by-product compensated for a decline in synthetic production. In 1977, production fell from its 1976 level of 2447 Gg to 2153 Gg. The cutback was generated by a reduction in caprolactam by-product AS. Output again fell in 1978 to 2116 Gg.

8.1.3. Domestic Consumption

Domestic consumption of AS increased at an average annual rate of 1.29 percent between 1955 and 1978, from 1495 Gg in 1955 to 2007 Gg in 1978. The increase in domestic AS consumption has been much smaller than the increase over the same period in total nitrogen consumption by the agricultural sector. Total nitrogen consumption rose from 1779 Gg in 1955 to 9048 Gg in 1978, an average annual increase of 7.33 percent. During this period the share of domestic agricultural consumption of nitrogen provided by AS fell from 17.65 percent to 4.65 percent. Between 1955 and 1969 AS consumption was relatively stable, fluctuating between 1305 Gg (1957) and 1706 Gg (1964). In 1970, domestic consumption of AS increased as exports fell and by-product output increased, rising from 1504 Gg in 1969 to 2054 Gg in 1970. Since 1970, output has fluctuated from year to year, peaking at 2267 Gg in 1971 and 2250 Gg in 1973. No long run growth trend for consumption of AS has emerged over this period, although sulfur deficiencies in the content of cultivated soils may generate some increase in domestic demand for the product over the next five to ten years. In this context, it is worth noting that of the total domestic consumption of AS in 1978, 48 percent (390 Gg) went to the Pacific Region of the United States where soil-sulfur content is low. The Appalachian States on the other hand, accounted for only 56 percent (4.6 Gg) of total U.S. direct application ammonium sulfate consumption.[27]

8.1.4. Prices*

Ammonium sulfate prices dropped steadily over the period 1955-1959 from $49.52 in 1955 to $36.15 in 1959 (see table 8-10). The price fall corresponded with a period of contracting domestic demand and declining exports. In 1960 market prices rose sharply to $63.82 as domestic consumption increased. Prices remained stable in 1961, but fell back to $62.83 in 1962 as domestic consumption again declined. Over the period 1963-1973 prices remained relatively stable, ranging from $56.99 in 1971 to $60.85 in 1973. In 1974, the price of AS almost doubled, rising to $121.25 as the price of natural gas increased, reflecting its diminished availability. Prices peaked in 1975 at $163.14, and then began to taper off. By 1978 the prices had fallen to $122.80.

8.1.5. International Trade

Over the period 1955-1978 the U.S. both imported and exported AS. However in all but one of those years (1961) it has been a net exporter of the product. Net exports have varied greatly from year to year, being extremely low in 1960 (24 Gg) and 1978 (60 Gg), and negative in 1961 (-93 Gg), but being relatively large in 1966 (1316 Gg) and 1968 (1147 Gg) (see Table 8-9).

Exports were more variable than imports during the period ranging from a low of 131 Gg in 1961 to a high of 1461 in 1966.

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*Prices presented in this section are per megagram of AS.

greatly from year to year, being extremely low in 1960 (24 Gg) and 1978 (60 Gg), and negative in 1961 (-93 Gg), but being relatively large in 1966 (1316 Gg) and 1968 (1147 Gg) (see table 8-9).

Table 8-10. Ammonium Sulfate Prices
(Dollars per megagram)

Year	Domestic Price	Export Price
1955	49.52	49.75
1956	40.47	45.79
1957	36.55	41.52
1958	36.51	38.75
1959	36.51	35.66
1960	63.82	31.13
1961	64.15	38.57
1962	62.83	33.94
1963	57.54	36.41
1964	57.98	39.83
1965	58.86	45.33
1966	58.20	46.76
1967	59.74	45.26
1968	59.41	38.59
1969	57.87	38.54
1970	57.76	17.01
1971	56.99	15.50
1972	57.43	29.71
1973	60.85	32.09
1974	121.25	74.74
1975	163.14	73.30
1976	110.88	45.30
1977	115.40	41.80
1978	122.80	60.85

*NA - not available

SOURCES

U.S. Department of Agriculture, Statistical Reporting Service. Agricultural Prices, 1955-1960.

U.S. Department of Agriculture, Economics Research Service. The Changing U.S. Fertilizer Industry. Agricultural Economic Report No. 378. August, 1977, p. 53, table 7.

U.S. Department of Commerce, Bureau of the Census. U.S. Exports Schedule B-Commodity and Country Report FT-410, 1955-1959.

British Sulphur Corporation, Half Yearly Export Price Indications for Ammonium Sulphate, 1963-1974, 1967-1978.

Between 1955 and 1961, exports fell from 555 Gg to 131 Gg. However, in the early sixties they began to rise as 1) demand for fertilizer in third world countries increased, 2) production capacity in the U.S. rose, and 3) U.S. AID programs to subsidize fertilizer exports to developing countries were implemented.

After 1966, export levels declined following a deemphasis of export subsidies for fertilizers and a rise in the nitrogenous fertilizer capacity in major U.S. export markets, particularly Latin America. Since 1970, export levels have been relatively stable, ranging from 355 Gg in 1978 to 682 Gg in 1976. Average annual exports from 1970-1978 were 490 Gg.

The level of imports was much less variable than the level of exports from 1955-1978. In all but one year, 1976, imports ranged from 119 Gg to 297 Gg. The 1976 level of imports was unusually large in 1976 (513 Gg), stimulated by a record level of domestic demand for nitrogenous fertilizer. Imports fell back to more typical levels in 1977 (297 Gg) and 1978 (295 Gg), although they were still in excess of the annual average level of imports (209 Gg) for the period 1955-1978.

8.1.6. Market Structure

8.1.6.1. Firm Characteristics

The firms involved in the production of AS are, by and large, vertically and/or horizontally integrated companies for whom AS production is not a major source of revenue. Though this is particularly true of by-product manufacturers, it also holds for prime producers, many of whom manufacture other fertilizers and chemicals. Most of the firms are relatively large (e.g. Allied, U.S. Steel, Nipro, BASF), and some are multinational corporations. Because of the diverse nature of the other activities of the firms involved in AS production (steel production, industrial chemicals, fertilizer, etc.) profits vary considerably among these companies (see table 8-11). However, in

Table 8-11. Financial Parameters for Selected Companies

Company	Year	AS Process	After Tax-Returns on Equity	Net Worth/Debt Ratio
Standard Oil Co. of California Chevron Chemical Co. Subsidiary	1977	Synthetic	13.31%	1.06
Occidental Petroleum Corporation - Hooker Chemical Corp. Subsidiary	1977	Synthetic	13.23%	0.70
Richardson-Merrell, Inc., J. T. Baker Co., subsidiary	1978	Synthetic	14.29%	1.56
Allied Chemical Corp., Fibers Division	1977	Caprolactam	11.3%	0.71

SOURCES

Securities and Exchange Commission. 10K Forms.

1977 profit levels appeared to provide an adequate rate of return on equity for several of the companies, ranging from 11.3 percent to 14.29 percent for the four companies for which data was available.

8.1.6.2. Market Concentration

The domestic AS industry is highly concentrated with the largest four firms controlling 53.5 percent and the top eight firms 70 percent of total AS capacity (see table 8-12). The industry is, in fact, dominated by the three caprolactam by-product producers - Allied, Nipro, and BASF. Since future industry growth is likely to be concentrated in this sector, industry concentration will probably increase over the next five to ten years, although it has been relatively stable since 1970. Consequently, the structure of the supply industry suggests that quasi-monopoly pricing behavior may become a possibility. However, the product itself faces strong competition from close substitutes such as urea and ammonium nitrate in the nitrogenous fertilizer market, and this strong interproduct competition limits the ability of dominant AS producers to manipulate product price.

8.1.7. Supply and Demand

8.1.7.1. Supply

No attempt was made to develop an econometric model of the AS industry. Nevertheless, it is clear that the production of AS is heavily influenced by its own price and the price of key inputs. For the prime product sector such inputs include sulfuric acid and anhydrous ammonia, labor, machinery and equipment. In the case of coke oven by-product AS, an important consideration is the value of alternative by-products such as anhydrous ammonia, ammonia liquor and diammonium phosphate.

Table 8-12. Industry Concentration of Ammonium Sulfate Producers (Share of total production capacity)

# of firms Year	Largest Four Firms	Largest Eight Firms	Largest Ten Firms	Largest Twenty Firms	Largest Forty Firms
1970	52%	68%	73.5%	87%	99%
1978	54	70	76	88	98
1979	53.5	70	76	88	98

SOURCE: Research Triangle Institute.

Increases in the prices of these alternative by-products relative to the price of AS and the development of new technologies for their manufacture resulted in a decline in the production of coke oven by-product AS. A critical variable in the caprolactam by-product sector is the price of caprolactam itself. As the price of caprolactam increases, stimulating the production of that product, the output of by-product AS increases. It should be noted that caprolactam is the more valuable of the two products. Its current (1979) market price is $1399.92 per metric ton, compared with $71.65 per metric ton for AS.[28]

8.1.7.2. Demand

Econometric techniques were used to analyze time series data on the domestic consumption of AS for 1955-1977.* The objective was to investigate the impact on consumption of changes in the prices of AS and substitute commodities, technical innovation and the level of output in the agricultural sector, the major user of AS. A number of different specifications of the relationship beteen AS consumption and the various possible explanatory variables were considered in the analysis. The two most satisfactory estimated equations are presented below. These equations attempt to explain the share of total nitrogen fertilizer consumption accounted for by AS in terms of its own price, the price of ammonium nitrate, the price of anhydrous ammonia and a time trend. The time trend was included to allow for the possibility of technical change. The estimated equations are:

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*Data on AS consumption and product prices is presented in tables 8-5, 8-7 and 8-10.

$$(1)\quad \log \frac{CAS}{N} = \underset{(1.23)}{-1.92}\ \underset{(1.23)}{-2.78^{**}} \log PAS + \underset{(1.05)}{2.40^{**}} \log PAN$$

$$+ \underset{(0.05)}{0.002} \log T\ ;\ R^2 = 0.51,$$

$$(2)\quad \log \frac{CAS}{N} = -3.50 - \underset{(1.22)}{2.60^{**}} \log PAS + \underset{(0.88)}{1.87^{**}} \log PAA$$

$$+ \underset{(0.06)}{0.04} \log T;\ R^2 = 0.50,$$

where,

CAS = domestic consumption of ammonium sulfate measured in terms of its nitrogen content,

N = total domestic consumption of nitrogen fertilizer,

PAS = price of ammonium sulfate

PAA = price of anhydrous ammonia,

PAN = price of ammonium nitrate,

T = time,

R^2 = the coefficient of multiple correlation,

log = natural logarithms.

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[*] The two equations presented here were most satisfactory in the sense that they accounted for more of the variation in the data than any other estimated equation for which the coefficients attached to the price variables were of expected sign and significance at the 5% level. In addition, in both cases the Durbin-Watson statistics provided no support for the hypothesis that serial correlation existed in the error structure.

[**] These coefficients are significantly different from zero at the 95 percent confidence level.

The figures in parentheses are the standard errors of the estimated coefficients. Each of the above equations explains approximately fifty percent of the variation in AS consumption over the period 1955-1977.* They are, therefore, not satisfactory tools for purposes of forecasting future trends in ammonium sulfate consumption. However, the results do indicate that the price of ammonium sulfate itself and the prices of substitute products such as anhydrous ammonia and ammonium nitrate strongly influence AS consumption. Equations (1) and (2) suggest that a one percent increase in the price of AS reduces the size of its share of the nitrogen fertilizer market by between 2.6 and 2.78 percent. On the other hand, a one percent increase in the price of the substitute nitrogen fertilizer** increases ammonium sulfate's share in the nitrogen fertilizer market by between 1.8 and 2.4 percent. Own-price and cross-price impacts appear to be substantial, supporting the view that a great deal of interaction takes place between the markets for the different nitrogenous fertilizers.

Finally, it should be noted that in the estimated equations the time trend included to account for technological change explained virtually none of the variation in the share of AS in total nitrogen consumption. However, this result should not be interpreted as positive evidence that consumption of AS was not influenced by product innovation in the fertilizer industry. The data used in the analysis exhibited the statistical problem of severe multicollinearity among the explanatory variables (in particular among fertilizer prices). Consequently, only the very simple equations presented above provided partially satisfactory results.

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*The R^2 coefficient measures the fraction of the sample period variation in the dependent variable explained by the estimated equation.

**The prices of ammonium nitrate, urea and anhydrous ammonia have been highly correlated over the past 25 years because they use common inputs. Thus we may regard movements in the price of one of these fertilizers as representative of changes in the prices of them all.

8.1.8. Baseline Projections

8.1.8.1. Baseline Regulatory Environment

The industry is assumed to be in compliance with existing State Implementation Plan (SIP) regulations prior to enforcement of any new source performance standard.

8.1.8.2. Baseline Growth Rates

Industry sources estimate that the annual rate of growth for AS consumption will be approximately 1 percent per year. However, there will be considerable variation in the growth rates experienced by the three major sectors in the industry.

Synthetic. No growth is expected in this sector in the five years following 1980 (1981-1985). However, although none of the existing plants have definite plans to modify or reconstruct their facilities, two producers may need to replace their dryers.

Coke Oven By-Product. Output from this sector is expected to decline in the five years following 1980 though the rate of decrease is not known. No new plants are forecast, and it is unlikely that more than four plants will implement major modification or reconstruction programs in the five year period 1981 through 1985. The forty coke oven plants currently producing AS use dryers with expected lives of

20-50 years. On average, each year only one or two plants will need to replace dryers. Thus, over a five-year period, only six to ten plants will have to consider retrofitting new equipment, and at least half of these plants are likely to close if the downtrend in coke oven production continues. (Between 1973 and 1978 the number of operational coke oven by-product plants fell from 46 to 40).

Caprolactam By-Product. The growth rate for caprolactam production is forecast to be between 5 and 7 percent over the period 1979-1985. It was noted in section 8.1.1 that in 1977 caprolactam production was 394 Gg, while industry capacity was 511 Gg. A 6.1 percent growth rate for caprolactam implies that caprolactam output will be 633 Gg in 1985. Two new caprolactam plants would be needed to provide the additional 122 Gg of caprolactam production capacity required to meet projected 1985 production levels and provide measurable excess capacity. Each plant would have a caprolactam capacity of approximately 115 Gg and an AS capacity of 380 Gg. In addition to these new plants, an existing facility will probably have to replace its drying equipment in the five-year period 1981 through 1985. Thus a total of three caprolactam plants will have to install emissions control in order to meet the emissions limits established by any promulgated regulation.

8.1.8.3. Baseline Projections of New, Modified and Reconstructed Facilities

The total number of new and reconstructed facilities projected under baseline conditions is summarized below:

	Affected Facilities
Synthetic	2
Coke Oven By-Product	4
Caprolactam By-Product	3

8.2 COST ANALYSIS OF ALTERNATIVE CONTROL SYSTEMS

This section presents an analysis of the costs of alternative control systems for dryers in three major segments of the ammonium sulfate industry. The control systems considered are fabric filter, venturi scrubber, and low-energy scrubber; the branches of the industry are the caprolactam byproduct, prime production, and coke oven byproduct segments.

The approach taken in determining the costs involved three steps; (1) determination of representative model plant parameters directly related to control costs; (2) application of the selected control systems to each segment of the industry; and (3) assessment of the total costs for the application of each control system at each typical dryer exhaust rate. The analysis includes total capital and annualized costs for each control system and also the incremental cost and cost-effectiveness of those systems capable of meeting the most stringent emission limitation. Results of this analysis will be used in determining the economic impacts of the control systems in Section 8.4.

The particulate control systems are designed in accordance with the model plant parameters furnished in Section 6 and shown in Tables 8-13 and 8-14. Tables 8-13 presents the production capacities of ammonium sulfate dryers and the corresponding exhaust gas volumes for the three segments of the industry. As shown in the table, dryers with the same production capacity may have different exhaust gas rates.

Model plant particulate emission parameters are shown in Table 8-14 functions of dryer production capacity and gas exhaust rates. The table sets forth the levels of uncontrolled emissions and those permitted by State Implementation Plans (SIP) and Option II with one exception, uncontrolled particulate emissions are estimated at 12.5 g/Nm^3 (5 gr/dscf), a value derived by back-calculation from emission levels at an assumed 99.6 percent removal efficiency. The exception is Case 1, the 27.2-Mg/h (30-ton/h) dryer, for which the value is based on actual plant data.

The Option II offers two formats, one regulating the mass particulate emissions and one limiting the concentration. As shown in Tables 8-13, the control level stipulated by either of the Option II formats is much more rigorous than those required by SIP. For this reason, the alternative control systems are

TABLE 8-13. PRODUCTION AND EXHAUST GAS RATES FOR MODEL PLANT AMMONIUM SULFATE DRYERS

Case	Industry segment	Ammonium sulfate production capacity per dryer Mg/h	(tons/h)	No. of control systems	No. of dryers	Dryer gas exhaust rate[a] per dryer unit Nm^3/min	(dscfm)	m^3/min	(acfm)
1	Caprolactam	27.2	(30)	2	2	1216	(42,500)	1500	(52,900)
2		22.7	(25)	2	2	58.9	(2,083)	71.5	(2,529)
3		22.7	(25)	2	2	235.8	(8,333)	294.0	(10,383)
4		22.7	(25)	2	2	589.6	(20,833)	735.0	(25,958)
5		22.7	(25)	2	2	943.3	(33,333)	1184.0	(41,533)
6	Prime	13.6	(15)	1	1	35.4	(1,250)	44.1	(1,558)
7		13.6	(15)	1	1	141.5	(5,000)	176.3	(6,230)
8		13.6	(15)	1	1	353.8	(12,500)	440.8	(15,575)
9		13.6	(15)	1	1	566.0	(20,000)	705.2	(24,920)
10	Coke oven	2.7	(3)	1	1	7.1	(250)	8.8	(312)
11		2.7	(3)	1	1	28.3	(1,000)	35.3	(1,246)
12		2.7	(3)	1	1	70.8	(2,500)	88.2	(3,115)
13		2.7	(3)	1	1	113.2	(4,000)	134.4	(4,764)

[a] Based on dryer exhaust conditions of 79°C (175°F) and 4 percent by volume water vapor.

Table 8-14. PARTICULATE EMISSION PARAMETERS FOR MODEL PLANT AMMONIUM SULFATE DRYERS

Case	Industry Segment	Ammonium Sulfate Production Capacity Per Dryer		Number of Control Systems	Number of Dryers	Particulate Emission Rates Per Dryer							
						No Control[a]		SIP Regulation[b]		Option II Format[c]		Option II Format[d]	
		Mg/h	(tons/h)			kg/h	(lb/h)	kg/h	(lb/h)	kg/h	(lb/h)	kg/h	(lb/h)
1	Caprolactam	27.2	(30)	2	2	2487	(6270)[e]	18.2	(40.0)	4.1	(9.0)	3.31	(7.29)[e]
2		22.2	(25)	2	2	40.5	(89.3)	16.1	(35.4)	3.4	(7.5)	0.16	(0.36)
3		22.7	(25)	2	2	162	(357)	16.1	(35.4)	3.4	(7.5)	0.65	(1.43)
4		22.7	(25)	2	2	405	(893)	16.1	(35.4)	3.4	(7.5)	1.62	(3.57)
5		22.7	(25)	2	2	647	(1427)	16.1	(35.4)	3.4	(7.5)	2.59	(5.71)
6	Prime	13.6	(15)	1	1	24.3	(53.5)	11.4	(25.2)	2.0	(4.5)	0.10	(0.21)
7		13.6	(15)	1	1	97	(214)	11.4	(25.2)	2.0	(4.5)	0.39	(0.86)
8		13.6	(15)	1	1	243	(535)	11.4	(25.2)	2.0	(4.5)	0.97	(2.14)
9		13.6	(15)	1	1	388	(856)	11.4	(25.2)	2.0	(4.5)	1.55	(3.42)
10	Coke Oven	2.7	(3)	1	1	4.8	(10.7)	3.9	(8.6)	0.4	(0.9)	0.02	(0.04)
11		2.7	(3)	1	1	19.4	(42.8)	3.9	(8.6)	0.4	(0.9)	0.08	(0.17)
12		2.7	(3)	1	1	48.5	(107)	3.9	(8.6)	0.4	(0.9)	0.20	(0.43)
13		2.7	(3)	1	1	78.0	(172)	3.9	(8.6)	0.4	(0.9)	0.31	(0.69)

[a] Back-calculated from controlled outlet emission rates; based on the particulate removal efficiency of 99.6 percent.

[b] Allowable emission rate under process weight regulation of a typical SIP; calculated from equation: lb/h emissions = $4.10(P)^{0.67}$, where P is the process rate expressed in tons/h.

[c] Based on a controlled emission rate of 0.15 kg/Mg (0.3 lb/ton).

[d] Based on a controlled emission rate of 0.05 g/m^3 (0.02 gr/dscf) of exhaust gas.

[e] Values determined from actual plant tests in which exhaust gas flows and particulate concentrations from a medium-energy venturi scrubber were measured.

designed to meet Option II requirements. The standards used are those governing particulate concentration in the effluent gas stream. Because both Option II formats require equivalent removal efficiency levels, the costs and cost-effectiveness of complying with either regulatory format are considered the same.

The control systems for which estimates were made are as discussed in Chapter 6. Table 8-15 describes the three alternative control systems: the fabric filter, the venturi scrubber, and the low-energy scrubber.

8.2.1 New Facilities

8.2.1.1 Capital and Annualized Operating Costs of Control Systems--

The capital and annual operating costs for each control system depend on the exhaust gas rate from the dryer. This rate varies significantly among segments of the ammonium sulfate industry and also within each segment. Cost estimates applicable to all types and sizes of dryers are obtained by consideration of the following exhaust gas rates:

m^3/min	(acfm)
8.5	(300)
28.3	(1,000)
283	(10,000)
1,189	(42,000)
1,698	(60,000)

Capital cost estimates are developed by (1) determining basic equipment costs, f.o.b.; (2) developing component factors for capital costs based on equipment costs; and (3) applying the cost component factors to the basic equipment costs to obtain total capital costs. The capital costs represent the total investment required for purchase and installation of the basic control equipment and associated auxiliaries, including equipment for dust recovery. No attempt is made to include either costs of research and development or costs of possible production losses during equipment installation and startup. The installation period for a control system is estimated to be approximately 2 months. Because little information is available regarding construction interest charges for such a short installation time, such charges are not included. All costs are stated in mid-1978 dollars and are based on equipment costs obtained from manufacturers.

TABLE 8-15. SPECIFICATIONS FOR EMISSION CONTROL SYSTEMS

I. Fabric filter

- A. Bag medium: Dacron felt
- B. Air-to-cloth ratio: 4:1
- C. Cleaning mechanism: reverse jet (heated)
- D. Units requiring insulation: dryer, ductwork, and baghouse
- E. Operating temperatures
  - 1. Inlet and outlet: 79°C (175°F)
  - 2. Dew point: 51°C (123°F) at 12.6 volume percent of water vapor (maximum)
- F. Pressure drop: 15.2 cm (6 in.) H_2O (suction baghouse)
- G. Fan location: discharge of baghouse
- H. Construction material:
  - a. fiberglass-reinforced plastic
  - b. carbon steel
- I. Typical duct distances between dryer and fabric filter
  - 1. Caprolactam byproduct: 12.2 m (40 ft)
  - 2. Prime product: 6.1 m (20 ft)
  - 3. Coke oven byproduct: 3.0 m (10 ft)

II. Venturi scrubber

- A. Pressure drop: 30.5 cm (12 in.) H_2O (pressure venturi)
- B. Fan location: between dryer and scrubber
- C. Liquid-to-gas ratio: 0.37 m^3/100 m^3 (28 gal/10^3 ft^3)
- D. Operating temperatures
  - 1. Inlet: 79°C (175°F)
  - 2. Outlet: 43°C (110°F)
- E. Construction material: fiberglass-reinforced plastic
- F. Typical duct distances between dryer and venturi scrubber
  - 1. Caprolactam byproduct: 15.2 m (50 ft)
  - 2. Prime product: 9.1 m (30 ft)
  - 3. Coke oven byproduct: 4.6 m (15 ft)

III. Typical low-energy scrubber used to meet process weight regulations

- A. Scrubber type: centrifugal, having no moving parts
- B. Pressure drop: 5-13 cm (2-6 in.) H_2O
- C. Operating temperatures
  - 1. Inlet: 79°C (175°F)
  - 2. Outlet: 43°C (110°F)
- D. Liquid-to-gas ratio: 0.27-0.68 m^3/100 m^3 (2-5 gal/10^3 ft^3)

Annualized costs represent the cost of operating and maintaining a control system plus the cost of recovering the capital investment required for the system. They include direct costs (utilities, operating labor, and maintenance), indirect costs (capital charges, overhead, and fixed costs), and credits for recovery of marketable particulate dust. Table 8-16 presents the assumptions made in estimating annualized costs.

Table 8-17 presents estimates of unit costs, f.o.b., for the basic equipment of a control system. The estimates represent actual costs obtained directly from equipment manufacturers.

The cost of a fabric filter unit includes the costs of the filter bags, air cleaning system, screw conveyor and air lock, fan, dampers, and pumps. Also included in the cost is a mix tank fitted with an agitator for mixing collected dust. The filter bags are dacron felt, and the materials of construction for the total system are either fiberglass-reinforced plastic (FRP) or carbon steel [referred to as standard construction material (STD)]. It is recommended that the carbon steel used be coated to protect against corrosion. According to published data, exposure of mild steel to a 10 to 30 weight percent solution of ammonium sulfate at temperatures ranging from 50° to 75°C (122 to 167°F) results in a corrosion rate of at least 50 mils (0.05 inch) per year.[35] At this rate, carbon steel components with a corrosion allowance of 0.125 inch would have an expected life of 2.5 years.

The cost of a venturi scrubber unit includes the costs of the scrubber, mist eliminator, fan, dampers, circulating pumps, and mix tank with cover. The material of construction is FRP.

The cost of a low-energy scrubber unit includes the scrubber, circulating pumps, and a mix tank with cover. The scrubber is made of polyvinyl chloride.

Tables 8-18 through 8-27 present the capital cost factors for fabric filters of FRP and STD construction. Tables 8-28 through 8-32 present the capital cost factors for a venturi scrubber, and Tables 8-33 through 8-37 present the capital cost factors for a low-energy scrubber. These factors are based on information obtained from control system manufacturers and on PEDCo engineering experience. The factor by which equipment costs are multiplied to obtain total capital costs is called the equipment cost multiplier.

TABLE 8-16. BASES FOR ESTIMATING ANNUALIZED COSTS FOR EMISSION CONTROL SYSTEMS[a]
(mid-1978 dollars)

	Unit cost
Direct operating costs	
Utilities	
Water	$0.0625/m^3$ ($0.25/$10^3$ gal)
Electricity	$0.03/kWh
Operating labor	
Direct	$7.25/h
Supervision	15% of direct labor
Maintenance	
Labor	115% of operating labor
Material	Equal to operating labor
Miscellaneous	Cost of bag replacement every 4 yrs.
Capital charges	
Overhead	
Plant	50% of operating and maintenance labor plus maintenance materials
Payroll	20% of operating labor
Fixed costs	
Capital recovery	14.67% of total capital costs[b]
Taxes and insurance	2.0% of total capital costs
Administration and permits	2.0% of total capital costs
Recovery credits	
Reprocessed ammonium sulfate	$53/Mg ($48/ton)[c]

[a] Estimates are for the control system and associated solid waste disposal equipment. Calculations are based on the following operating factors: caprolactam, 8400 h/yr; prime product, 5400 h/yr; coke oven byproduct, 7400 h/yr.

[b] Based upon a 12 yr life and a 10% interest rate.

[c] Based on a market price of $66.14/Mg with a 20% discount for reprocessing costs.

TABLE 8-17. COSTS OF PARTICULATE EMISSION CONTROL EQUIPMENT FOR THE AMMONIUM SULFATE INDUSTRY[a] (mid-1978 dollars)

Equipment type	Exhaust gas flow rate				
	8.5 m^3/min (300 acfm)	28.3 m^3/min (1000 acfm)	283 m^3/min (10,000 acfm)	1,189 m^3/min (42,000 acfm)	1,698 m^3/min (60,000 acfm)
Fabric filter					
FRP	10,700	20,700	120,600	499,200[b]	623,700
STD	7,400	10,600	29,300	69,800	87,600
Venturi scrubber	6,000	9,500	21,300	74,500	98,100
Low-energy scrubber	6,700	6,900	13,800	33,500	48,300

[a] Costs calculated f.o.b. site.

[b] Cost of a system containing four fabric filters in parallel.

TABLE 8-18. COMPONENT CAPITAL COST FACTORS FOR FRP FABRIC FILTER 8.5 m^3/min (300 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.009	0.033	0.042	
Duct work	0.028	0.018	0.046	
Instrumentation	0.097	0.029	0.126	
Piping	0.075	0.179	0.254	
Electrical work	0.188	0.122	0.310	
Foundations	0.068	0.068	0.136	
Structural work	0.218	0.049	0.267	
Site work	0.005	0.005	0.010	
Insulation	0.052	0.077	0.129	
Painting	0.007	0.042	0.049	
Other				
Total Direct Cost Factor	1.747	0.622		2.369

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.237	
Contractor's overhead and profit	26.5% of total direct costs	0.628	
Shakedown	5% of direct costs	0.118	
Spares	1% of direct material cost only	0.002	
Freight	3% of direct material cost only	0.052	
Taxes	3% of direct material cost only	0.052	
Other			
Total Indirect Cost Factor			1.089
Contingencies	20% of total direct and indirect costs		0.692
TOTAL EQUIPMENT COST MULTIPLIER			4.150

TABLE 8-19. COMPONENT CAPITAL COST FACTORS FOR FRP FABRIC FILTER--28.3 m^3/min (1000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.005	0.026	0.031	
Duct work	0.019	0.012	0.031	
Instrumentation	0.050	0.015	0.065	
Piping	0.039	0.092	0.131	
Electrical work	0.097	0.063	0.016	
Foundations	0.052	0.052	0.104	
Structural work	0.182	0.042	0.224	
Site work	0.003	0.003	0.006	
Insulation	0.043	0.068	0.111	
Painting	0.006	0.036	0.042	
Other				
Total Direct Cost Factor	1.496	0.409		1.905

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.191	
Contractor's overhead and profit	26.5% of total direct costs	0.505	
Shakedown	5% of direct costs	0.095	
Spares	1% of direct material cost only	0.015	
Freight	3% of direct material cost only	0.045	
Taxes	3% of direct material cost only	0.045	
Other			
Total Indirect Cost Factor			0.896
Contingencies	20% of total direct and indirect costs		0.560
TOTAL EQUIPMENT COST MULTIPLIER			3.361

TABLE 8-20. COMPONENT CAPITAL COST FACTORS FOR FRP FABRIC FILTER--283 m^3/min (10,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.002	0.006	0.008	
Duct work	0.012	0.010	0.022	
Instrumentation	0.013	0.004	0.017	
Piping	0.007	0.019	0.026	
Electrical work	0.026	0.015	0.041	
Foundations	0.030	0.030	0.060	
Structural work	0.045	0.010	0.055	
Site work	0.001	0.001	0.002	
Insulation	0.036	0.058	0.094	
Painting	0.001	0.009	0.010	
Other				
Total Direct Cost Factor	1.174	0.162		1.335

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.134	
Contractor's overhead and profit	26.5% of total direct costs	0.354	
Shakedown	5% of direct costs	0.067	
Spares	1% of direct material cost only	0.012	
Freight	3% of direct material cost only	0.035	
Taxes	3% of direct material cost only	0.035	
Other			
Total Indirect Cost Factor			0.637
Contingencies	20% of total direct and indirect costs		0.394
TOTAL EQUIPMENT COST MULTIPLIER			2.366

TABLE 8-21. COMPONENT CAPITAL COST FACTORS FOR FRP FABRIC FILTER--1,189 m^3/min (42,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.001	0.003	0.004	
Duct work	0.014	0.011	0.025	
Instrumentation	0.010	0.002	0.012	
Piping	0.002	0.005	0.007	
Electrical work	0.013	0.007	0.020	
Foundations	0.016	0.016	0.032	
Structural work	0.023	0.005	0.028	
Site work	0.001	0.001	0.002	
Insulation	0.029	0.046	0.075	
Painting	0.001	0.005	0.006	
Other				
Total Direct Cost Factor	1.110	0.101		1.211

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.121	
Contractor's overhead and profit	26.5% of total direct costs	0.321	
Shakedown	5% of direct costs	0.061	
Spares	1% of direct material cost only	0.011	
Freight	3% of direct material cost only	0.033	
Taxes	3% of direct material cost only	0.033	
Other			
Total Indirect Cost Factor			0.580
Contingencies	20% of total direct and indirect costs		0.358
TOTAL EQUIPMENT COST MULTIPLIER			2.149

TABLE 8-22. COMPONENT COST FACTORS FOR FRP FABRIC FILTER--1,698 m^3/min (60,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.0000		1.0000	
Site erection of equipment	0.0009	0.0027	0.0036	
Duct work	0.0152	0.0128	0.0280	
Instrumentation	0.0071	0.0015	0.0086	
Piping	0.0014	0.0036	0.0050	
Electrical work	0.0104	0.0058	0.0162	
Foundations	0.0144	0.0144	0.0288	
Structural work	0.0211	0.0048	0.0259	
Site work	0.0004	0.0004	0.0008	
Insulation	0.0247	0.0392	0.0639	
Painting	0.0007	0.0041	0.0043	
Other				
Total Direct Cost Factor	1.0963	0.0893		1.1856

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.119	
Contractor's overhead and profit	26.5% of total direct costs	0.3142	
Shakedown	5% of direct costs	0.0593	
Spares	1% of direct material cost only	0.0109	
Freight	3% of direct material cost only	0.0329	
Taxes	3% of direct material cost only	0.0329	
Other			
Total Indirect Cost Factor			0.5692
Contingencies	20% of total direct and indirect costs		0.3510
TOTAL EQUIPMENT COST MULTIPLIER			2.1058

TABLE 8-23. COMPONENT CAPITAL COST FACTORS FOR STD FABRIC FILTER--8.5 m^3/min (300 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.0000		1.0000	
Site erection of equipment	0.0135	0.0472	0.0607	
Duct work	0.0405	0.0270	0.0675	
Instrumentation	0.1399	0.0419	0.1818	
Piping	0.1081	0.2581	0.3662	
Electrical work	0.2703	0.1757	0.4460	
Foundations	0.0972	0.0973	0.1945	
Structural work	0.3142	0.0709	0.3851	
Site work	0.0676	0.0676	0.1352	
Insulation	0.0743	0.1182	0.1925	
Painting	0.0101	0.0608	0.0709	
Other				
Total Direct Cost Factor	2.1357	0.9647		3.1004

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.3100	
Contractor's overhead and profit	26.5% of total direct costs	0.8216	
Shakedown	5% of direct costs	0.1550	
Spares	1% of direct material cost only	0.0214	
Freight	3% of direct material cost only	0.0641	
Taxes	3% of direct material cost only	0.0641	
Other			
Total Indirect Cost Factor			1.4362
Contingencies	20% of total direct and indirect costs		0.9073
TOTAL EQUIPMENT COST MULTIPLIER			5.4439

TABLE 8-24. COMPONENT CAPITAL COST FACTORS FOR STD FABRIC FILTER--28 m^3/min (1000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.0000		1.0000	
Site erection of equipment	0.0099	0.0525	0.0624	
Duct work	0.0398	0.0250	0.0648	
Instrumentation	0.0130	0.0382	0.0512	
Piping	0.0795	0.1899	0.2694	
Electrical work	0.1989	0.1292	0.3281	
Foundations	0.1074	0.1074	0.2148	
Structural work	0.3750	0.0870	0.4620	
Site work	0.0059	0.0059	0.0118	
Insulation	0.0875	0.1390	0.2265	
Painting	0.0124	0.0750	0.0874	
Other				
Total Direct Cost Factor	1.9293	0.8491		2.7784

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.2778	
Contractor's overhead and profit	26.5% of total direct costs	0.7363	
Shakedown	5% of direct costs	0.1389	
Spares	1% of direct material cost only	0.0193	
Freight	3% of direct material cost only	0.0579	
Taxes	3% of direct material cost only	0.0579	
Other			
Total Indirect Cost Factor			1.2881
Contingencies	20% of total direct and indirect costs		0.8133
TOTAL EQUIPMENT COST MULTIPLIER			4.8798

TABLE 8-25. COMPONENT CAPITAL COST FACTORS FOR STD FABRIC FILTER--283 m^3/min (10,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.0000		1.0000	
Site erection of equipment	0.0068	0.0239	0.0307	
Duct work	0.0475	0.0493	0.0968	
Instrumentation	0.0517	0.0147	0.0664	
Piping	0.0190	0.0774	0.0964	
Electrical work	0.1057	0.0631	0.1688	
Foundations	0.0916	0.0916	0.1832	
Structural work	0.1850	0.0418	0.2268	
Site work	0.0034	0.0034	0.0068	
Insulation	0.1500	0.2387	0.3887	
Painting	0.0059	0.0358	0.0417	
Other				
Total Direct Cost Factor	1.6666	0.6397		2.3063

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.2306	
Contractor's overhead and profit	26.5% of total direct costs	0.6112	
Shakedown	5% of direct costs	0.1153	
Spares	1% of direct material cost only	0.0167	
Freight	3% of direct material cost only	0.0500	
Taxes	3% of direct material cost only	0.0500	
Other			
Total Indirect Cost Factor			1.0738
Contingencies	20% of total direct and indirect costs		0.6760
TOTAL EQUIPMENT COST MULTIPLIER			4.0561

TABLE 8-26. COMPONENT CAPITAL COST FACTORS FOR STD FABRIC FILTER--1189 m^3/min (42,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.0000		1.0000	
Site erection of equipment	0.0057	0.0201	0.0258	
Duct work	0.0974	0.0802	0.1776	
Instrumentation	0.0638	0.0135	0.0773	
Piping	0.0123	0.0325	0.0448	
Electrical work	0.0931	0.0516	0.1447	
Foundations	0.1160	0.1160	0.2320	
Structural work	0.1665	0.0376	0.2041	
Site work	0.0036	0.0036	0.0072	
Insulation	0.2049	0.3259	0.5308	
Painting	0.0054	0.0322	0.0376	
Other				
Total Direct Cost Factor	1.7687	0.7132		2.4819

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.2482	
Contractor's overhead and profit	26.5% of total direct costs	0.6577	
Shakedown	5% of direct costs	0.1241	
Spares	1% of direct material cost only	0.0.77	
Freight	3% of direct material cost only	0.0531	
Taxes	3% of direct material cost only	0.0531	
Other			
Total Indirect Cost Factor			1.1539
Contingencies	20% of total direct and indirect costs		0.7272
TOTAL EQUIPMENT COST MULTIPLIER			4.3630

TABLE 8-27. COMPONENT CAPITAL COST FACTORS FOR STD FABRIC FILTER--1698 m^3/min (60,000 acfm)

Description	Direct Costs			
	Components		Factor	
	Material	Labor	Total	Total
Equipment, f.o.b. manufacturer	1.0000		1.0000	
Site erection of equipment	0.0068	0.0191	0.0259	
Duct work	0.1084	0.0913	0.1997	
Instrumentation	0.0509	0.0107	0.0616	
Piping	0.0098	0.0259	0.0357	
Electrical work	0.0742	0.0411	0.1153	
Foundations	0.1030	0.1030	0.2060	
Structural work	0.1504	0.0340	0.1844	
Site work	0.0029	0.0029	0.0058	
Insulation	0.1758	0.2797	0.4555	
Painting	0.0049	0.0291	0.0340	
Other				
Total Direct Cost Factor	1.6871	0.6368		2.3239

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.2324	
Contractor's overhead and profit	26.5% of total direct costs	0.6158	
Shakedown	5% of direct costs	0.1162	
Spares	1% of direct material cost only	0.0169	
Freight	3% of direct material cost only	0.0506	
Taxes	3% of direct material cost only	0.0506	
Other			
Total Indirect Cost Factor			1.0825
Contingencies	20% of total direct and indirect costs		0.6813
TOTAL EQUIPMENT COST MULTIPLIER			4.0877

TABLE 8-28. COMPONENT CAPITAL COST FACTORS FOR VENTURI SCRUBBER--8.5 m^3/min (300 acfm)

Description	Direct Costs			
	Components		Factor	
	Material	Labor	Total	Total
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.008	0.029	0.037	
Duct work	0.030	0.020	0.050	
Instrumentation	0.111	0.035	0.146	
Piping	0.095	0.235	0.330	
Electrical work	0.225	0.145	0.370	
Foundations	0.045	0.045	0.090	
Structural work	0.193	0.043	0.236	
Site work	0.007	0.007	0.014	
Insulation				
Painting	0.007	0.037	0.044	
Other				
Total Direct Cost Factor	1.721	0.596		2.317

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.232	
Contractor's overhead and profit	26.5% of total direct costs	0.614	
Shakedown	5% of direct costs	0.116	
Spares	1% of direct material cost only	0.017	
Freight	3% of direct material cost only	0.052	
Taxes	3% of direct material cost only	0.052	
Other			
Total Indirect Cost Factor			1.083
Contingencies	20% of total direct and indirect costs		0.680
TOTAL EQUIPMENT COST MULTIPLIER			4.080

TABLE 8-29. COMPONENT CAPITAL COST FACTORS FOR VENTURI SCRUBBER--28.3 m^3/min (1000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.021	0.076	0.097	
Duct work	0.025	0.016	0.041	
Instrumentation	0.107	0.031	0.138	
Piping	0.084	0.202	0.286	
Electrical work	0.158	0.100	0.258	
Foundations	0.038	0.038	0.076	
Structural work	0.164	0.037	0.201	
Site work	0.011	0.011	0.022	
Insulation				
Painting	0.005	0.032	0.037	
Other				
Total Direct Cost Factor	1.613	0.543		2.156

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.216	
Contractor's overhead and profit	26.5% of total direct costs	0.571	
Shakedown	5% of direct costs	0.108	
Spares	1% of direct material cost only	0.016	
Freight	3% of direct material cost only	0.048	
Taxes	3% of direct material cost only	0.048	
Other			
Total Indirect Cost Factor			1.007
Contingencies	20% of total direct and indirect costs		0.633
TOTAL EQUIPMENT COST MULTIPLIER			3.796

TABLE 8-30. COMPONENT CAPITAL COST FACTORS FOR VENTURI SCRUBBER--283 m^3/min (10,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.019	0.066	0.085	
Duct work	0.039	0.034	0.073	
Instrumentation	0.048	0.014	0.062	
Piping	0.045	0.110	0.155	
Electrical work	0.160	0.092	0.252	
Foundations	0.051	0.051	0.102	
Structural work	0.182	0.041	0.223	
Site work	0.012	0.012	0.024	
Insulation				
Painting	0.006	0.035	0.041	
Other				
Total Direct Cost Factor	1.562	0.455		2.017
	Indirect Costs			
	Basis for factor		Factor	Total
Engineering	10% of total direct costs		0.202	
Contractor's overhead and profit	26.5% of total direct costs		0.534	
Shakedown	5% of direct costs		0.101	
Spares	1% of direct material cost only		0.016	
Freight	3% of direct material cost only		0.047	
Taxes	3% of direct material cost only		0.047	
Other				
Total Indirect Cost Factor				0.947
Contingencies	20% of total direct and indirect costs			0.593
TOTAL EQUIPMENT COST MULTIPLIER				3.557

TABLE 8-31. COMPONENT CAPITAL COST FACTORS FOR VENTURI SCRUBBER--1,189 m^3/min (42,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.005	0.038	0.043	
Duct work	0.027	0.023	0.050	
Instrumentation	0.014	0.004	0.018	
Piping	0.024	0.036	0.060	
Electrical work	0.145	0.077	0.222	
Foundations	0.029	0.029	0.058	
Structural work	0.104	0.024	0.128	
Site work	0.007	0.007	0.014	
Insulation				
Painting	0.003	0.020	0.023	
Other				
Total Direct Cost Factor	1.358	0.258		1.616
	Indirect Costs			
	Basis for factor		Factor	Total
Engineering	10% of total direct costs		0.162	
Contractor's overhead and profit	26.5% of total direct costs		0.428	
Shakedown	5% of direct costs		0.081	
Spares	1% of direct material cost only		0.014	
Freight	3% of direct material cost only		0.047	
Taxes	3% of direct material cost only		0.047	
Other				
Total Indirect Cost Factor				0.767
Contingencies	20% of total direct and indirect costs			0.477
TOTAL EQUIPMENT COST MULTIPLIER				2.860

TABLE 8-32. COMPONENT CAPITAL COST FACTORS FOR VENTURI SCRUBBER--1698 m^3/min (60,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.006	0.032	0.038	
Duct work	0.027	0.023	0.050	
Instrumentation	0.012	0.004	0.016	
Piping	0.027	0.035	0.062	
Electrical work	0.130	0.069	0.199	
Foundations	0.026	0.026	0.052	
Structural work	0.095	0.021	0.116	
Site work	0.005	0.005	0.010	
Insulation				
Painting	0.003	0.018	0.021	
Other				
Total Direct Cost Factor	1.331	0.233		1.564

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.156	
Contractor's overhead and profit	26.5% of total direct costs	0.414	
Shakedown	5% of direct costs	0.078	
Spares	1% of direct material cost only	0.013	
Freight	3% of direct material cost only	0.040	
Taxes	3% of direct material cost only	0.040	
Other			
Total Indirect Cost Factor			0.741
Contingencies	20% of total direct and indirect costs		0.461
TOTAL EQUIPMENT COST MULTIPLIER			2.766

TABLE 8-33. COMPONENT CAPITAL COST FACTORS FOR LOW-ENERGY SCRUBBER--8.5 m^3/min (300 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.008	0.026	0.034	
Duct work	0.027	0.018	0.045	
Instrumentation	0.100	0.031	0.131	
Piping	0.085	0.211	0.296	
Electrical work	0.202	0.130	0.332	
Foundations	0.040	0.040	0.080	
Structural work	0.174	0.039	0.213	
Site work	0.006	0.006	0.012	
Insulation				
Painting	0.006	0.034	0.040	
Other				
Total Direct Cost Factor	1.648	0.535		2.183

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.218	
Contractor's overhead and profit	26.5% of total direct costs	0.578	
Shakedown	5% of direct costs	0.109	
Spares	1% of direct material cost only	0.016	
Freight	3% of direct material cost only	0.049	
Taxes	3% of direct material cost only	0.049	
Other			
Total Indirect Cost Factor			1.019
Contingencies	20% of total direct and indirect costs		0.640
TOTAL EQUIPMENT COST MULTIPLIER			3.842

TABLE 8-34. COMPONENT CAPITAL COST FACTORS FOR LOW-ENERGY SCRUBBER--28.3 m^3/min (1000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.014	0.051	0.065	
Duct work	0.035	0.022	0.057	
Instrumentation	0.096	0.030	0.126	
Piping	0.083	0.204	0.287	
Electrical work	0.206	0.132	0.338	
Foundations	0.039	0.039	0.078	
Structural work	0.168	0.038	0.206	
Site work	0.006	0.006	0.012	
Insulation				
Painting	0.006	0.033	0.039	
Other				
Total Direct Cost Factor	1.653	0.555		2.208

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.221	
Contractor's overhead and profit	26.5% of total direct costs	0.585	
Shakedown	5% of direct costs	0.110	
Spares	1% of direct material cost only	0.017	
Freight	3% of direct material cost only	0.050	
Taxes	3% of direct material cost only	0.050	
Other			
Total Indirect Cost Factor			1.033
Contingencies	20% of total direct and indirect costs		0.648
TOTAL EQUIPMENT COST MULTIPLIER			3.889

TABLE 8-35. COMPONENT CAPITAL COST FACTORS FOR LOW-ENERGY SCRUBBER--283 m^3/min (10,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.015	0.038	0.053	
Duct work	0.061	0.052	0.113	
Instrumentation	0.074	0.021	0.095	
Piping	0.047	0.129	0.176	
Electrical work	0.153	0.098	0.251	
Foundations	0.033	0.033	0.066	
Structural work	0.169	0.038	0.207	
Site work	0.004	0.004	0.008	
Insulation				
Painting	0.006	0.033	0.039	
Other				
Total Direct Cost Factor	1.562	0.446		2.008

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.201	
Contractor's overhead and profit	26.5% of total direct costs	0.532	
Shakedown	5% of direct costs	0.100	
Spares	1% of direct material cost only	0.016	
Freight	3% of direct material cost only	0.047	
Taxes	3% of direct material cost only	0.047	
Other			
Total Indirect Cost Factor			0.943
Contingencies	20% of total direct and indirect costs		0.590
TOTAL EQUIPMENT COST MULTIPLIER			3.541

TABLE 8-36. COMPONENT CAPITAL COST FACTORS FOR LOW-ENERGY SCRUBBER--1,189 m^3/min (42,000 acfm)

Description	Direct Costs			
	Components		Factor Total	Total
	Material	Labor		
Equipment, f.o.b. manufacturer	1.000		1.000	
Site erection of equipment	0.006	0.021	0.027	
Duct work	0.061	0.050	0.111	
Instrumentation	0.030	0.009	0.039	
Piping	0.019	0.053	0.072	
Electrical work	0.111	0.061	0.172	
Foundations	0.027	0.027	0.054	
Structural work	0.139	0.031	0.170	
Site work	0.002	0.002	0.004	
Insulation				
Painting	0.004	0.027	0.031	
Other				
Total Direct Cost Factor	1.399	0.281		1.680

	Indirect Costs		
	Basis for factor	Factor	Total
Engineering	10% of total direct costs	0.168	
Contractor's overhead and profit	26.5% of total direct costs	0.445	
Shakedown	5% of direct costs	0.084	
Spares	1% of direct material cost only	0.014	
Freight	3% of direct material cost only	0.042	
Taxes	3% of direct material cost only	0.042	
Other			
Total Indirect Cost Factor			0.795
Contingencies	20% of total direct and indirect costs		0.495
TOTAL EQUIPMENT COST MULTIPLIER			2.970

TABLE 8-37. COMPONENT CAPITAL COST FACTORS FOR LOW-ENERGY SCRUBBER--1698 m^3/min (60,000 acfm)

<table>
<tr><th rowspan="3">Description</th><th colspan="4">Direct Costs</th></tr>
<tr><th colspan="2">Components</th><th rowspan="2">Factor Total</th><th rowspan="2">Total</th></tr>
<tr><th>Material</th><th>Labor</th></tr>
<tr><td>Equipment, f.o.b. manufacturer</td><td>1.000</td><td></td><td>1.000</td><td></td></tr>
<tr><td>Site erection of equipment</td><td>0.005</td><td>0.018</td><td>0.023</td><td></td></tr>
<tr><td>Duct work</td><td>0.056</td><td>0.046</td><td>0.102</td><td></td></tr>
<tr><td>Instrumentation</td><td>0.025</td><td>0.007</td><td>0.032</td><td></td></tr>
<tr><td>Piping</td><td>0.034</td><td>0.060</td><td>0.094</td><td></td></tr>
<tr><td>Electrical work</td><td>0.125</td><td>0.068</td><td>0.193</td><td></td></tr>
<tr><td>Foundations</td><td>0.022</td><td>0.023</td><td>0.045</td><td></td></tr>
<tr><td>Structural work</td><td>0.128</td><td>0.029</td><td>0.157</td><td></td></tr>
<tr><td>Site work</td><td>0.002</td><td>0.001</td><td>0.003</td><td></td></tr>
<tr><td>Insulation</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Painting</td><td>0.004</td><td>0.022</td><td>0.026</td><td></td></tr>
<tr><td>Other</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total Direct Cost Factor</td><td>1.401</td><td>0.274</td><td></td><td>1.675</td></tr>
<tr><th rowspan="2"></th><th colspan="4">Indirect Costs</th></tr>
<tr><th colspan="2">Basis for factor</th><th>Factor</th><th>Total</th></tr>
<tr><td>Engineering</td><td colspan="2">10% of total direct costs</td><td>0.168</td><td></td></tr>
<tr><td>Contractor's overhead and profit</td><td colspan="2">26.5% of total direct costs</td><td>0.444</td><td></td></tr>
<tr><td>Shakedown</td><td colspan="2">5% of direct costs</td><td>0.084</td><td></td></tr>
<tr><td>Spares</td><td colspan="2">1% of direct material cost only</td><td>0.014</td><td></td></tr>
<tr><td>Freight</td><td colspan="2">3% of direct material cost only</td><td>0.042</td><td></td></tr>
<tr><td>Taxes</td><td colspan="2">3% of direct material cost only</td><td>0.042</td><td></td></tr>
<tr><td>Other</td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Total Indirect Cost Factor</td><td colspan="2"></td><td></td><td>0.794</td></tr>
<tr><td>Contingencies</td><td colspan="2">20% of total direct and indirect costs</td><td></td><td>0.494</td></tr>
<tr><td colspan="3">TOTAL EQUIPMENT COST MULTIPLIER</td><td></td><td>2.963</td></tr>
</table>

Figure 8-4 presents a comparison of the equipment cost multipliers for each control system at various exhaust gas rates.

Total control system costs (i.e., capital and annualized operating costs) are shown in Tables 8-38 through 8-41. Costs for the caprolactam industry are based on two pairs of dryers, one pair having a capacity of 22.7 Mg/h (25 tons/h), and the other pair having a capacity of 27.2 Mg/h (30 tons/h). Each dryer requires a separate control system. Costs for the prime industry and the coke oven byproduct industry are also based on the installation of one control system per dryer, but a plant requires only one dryer. Dryer capacities are assumed to be 13.6 Mg/h (15 tons/h) for the prime industry and 2.7 Mg/h (3 tons/h) for the coke oven byproduct industry. Where required, all costs are adjusted to mid-1978 dollars by use of the Chemical Engineering Cost Index.

A comparison of the investment (total capital) costs for each of the alternative control systems is given in Figure 8-5.

The captured particulate is reprocessed to recover ammonium sulfate, which has value as a source of nitrogen fertilizer. The value of the recovered material offsets some of the direct operating costs and capital charges. These recovery credits are particularly significant in the caprolactam byproduct industry, which is now the single largest manufacturing source of ammonium sulfate.

Annualized cost of operation of a control device is a function of the number of hours the dryer is operated per year. Dryers are assumed to operate at the following rates: 8400 h/yr for the caprolactam byproduct industry, 5400 h/yr for the prime production industry, and 7400 h/yr for the coke oven byproduct industry.

8.2.1.2 Product Dryer Costs--

Table 8-42 shows the costs of a fluidized-bed dryer and of a rotary drum dryer. Each dryer has a production capacity of 23 Mg/h (25 tons/h) and is indirectly heated by steam-heated air. Although a fluidized-bed dryer is sometimes thought to be less expensive to install and operate, this comparison does not take into account the added cost required for a cooling system. The capital cost of a fluidized-bed dryer with a cooling system is slightly

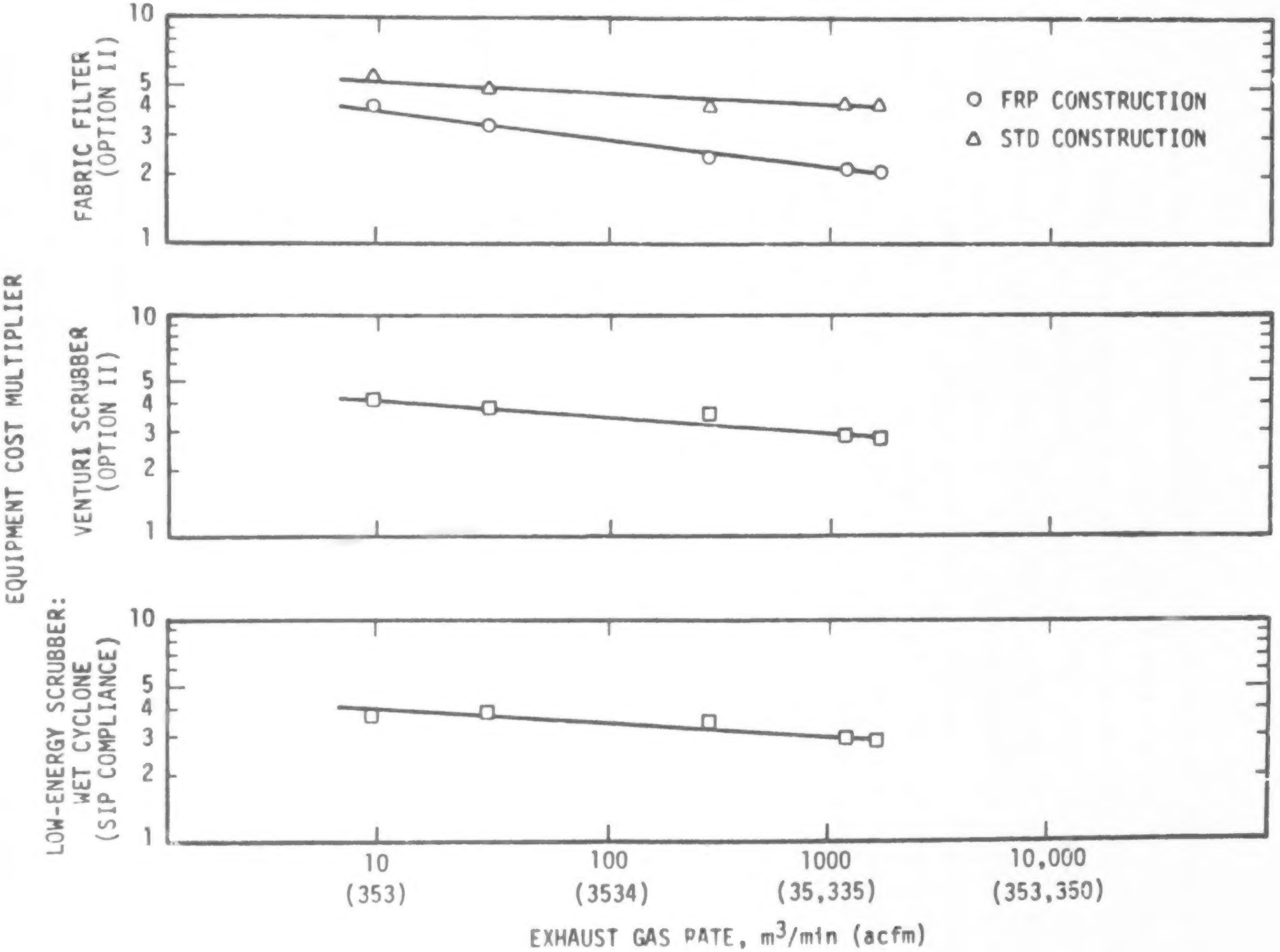

Figure 8-4. Cost multiplier factors for selected control equipment.

TABLE 8-38. COST OF CONTROL SYSTEMS: CAPROLACTAM BYPRODUCT INDUSTRY; 27.2-Mg/h (30 tons/h) DRYERS[a]

Regulation	System	Combined exhaust rate		Capital investment, \$1000[c]	Annualized costs[b]			
		m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Option I	Two low-energy scrubbers	3000	106,000	248	60.6	51.6	(2489.6)[d]	(2377.4)
Option II	Two fabric filters (FRP)	3000	106,000	2300	66.3	440.8	(2500.0)	(1992.9)
	Two fabric filters (STD)	3000	106,000	690	66.3	140.3	(2500.0)	(2293.4)
	Two venturi scrubbers	3000	106,000	500	162.2	99.0	(2500.0)	(2238.8)

[a] Two dryers are used; an individual system is needed for each dryer.

[b] Operating factor: 8400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-39. COST OF CONTROL SYSTEMS: CAPROLACTAM BYPRODUCT INDUSTRY; 22.7-Mg/h (25-ton/h) DRYERS[a]

Regulation	System	Combined exhaust rate		Capital investment, \$1000[c]	Annualized cost[b]			
		m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Option I	Two low-energy scrubbers	143	5,058	62	10.0	16.1	(21.7)[c]	4.4
		588	20,766	90	15.9	21.5	(129.7)	(92.3)
		1469	51,916	140	26.6	31.0	(345.8)	(288.2)
		2368	83,066	196	37.5	41.6	(561.1)	(482.0)
Option II	Two fabric filters (FRP)	143	5,058	206	9.2	43.2	(35.9)	16.4
		588	20,766	580	16.2	113.2	(143.4)	(14.0)
		1469	51,916	1360	31.2	254.0	(358.6)	(73.4)
		2368	83,066	2120	56.0	396.0	(573.0)	(121.0)
	Two fabric filters (STD)	143	5,058	145	9.2	31.8	(35.9)	5.2
		588	20,766	240	16.2	49.7	(143.3)	(77.4)
		1469	51,916	390	31.2	78.5	(358.6)	(248.9)
		2368	83,066	550	56.0	113.9	(573.0)	(403.1)
Option II	Two venturi scrubbers	143	5,058	90	13.4	21.6	(35.9)	(0.9)
		588	20,766	154	31.3	33.8	(143.4)	(78.3)
		1469	51,916	266	67.6	54.9	(358.6)	(236.1)
		2368	83,066	420	106.8	83.9	(573.0)	(382.3)

---

[a] Two dryers are used; an individual system is needed for each dryer.

[b] Operating factor: 8400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-40. COST OF CONTROL SYSTEMS: PRIME INDUSTRY[a]

Regulation	System	Exhaust rate		Capital investment, \$1000[c]	Annualized costs[b]			
		m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Option I	Low-energy scrubber	44.1	1,558	29	3.5	7.3	(3.7)[d]	7.1
		176.3	6,230	39	4.8	9.1	(24.5)	(10.6)
		440.8	15,575	53	6.9	11.8	(66.1)	(47.4)
		705.2	24,920	69	9.0	14.9	(107.7)	(83.8)
Option II	Fabric filter (FRP)	44.1	1,558	81	2.4	16.3	(6.9)	11.8
		176.3	6,230	199	4.4	38.7	(27.6)	15.5
		440.8	15,575	430	7.9	82.1	(69.1)	20.9
		705.2	24,920	650	11.2	123.5	(110.5)	24.2
	Fabric filter (STD)	44.1	1,558	62	2.4	12.8	(6.9)	8.3
		176.3	6,230	99	4.4	20.0	(27.6)	(3.2)
		440.8	15,575	145	7.9	29.0	(69.1)	(32.2)
		705.2	24,920	190	11.2	37.7	(110.5)	(61.6)
Option II	Venturi scrubber	44.1	1,558	40	4.2	9.4	(6.9)	6.7
		176.3	6,230	62	7.5	13.6	(27.6)	(6.5)
		440.8	15,575	95	14.5	19.8	(69.1)	(34.8)
		705.2	24,920	130	21.5	26.4	(110.5)	(62.6)

[a] For an ammonium sulfate dryer with a production capacity of 13.6 Mg/h (15 tons/h).

[b] Operating factor: 5400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

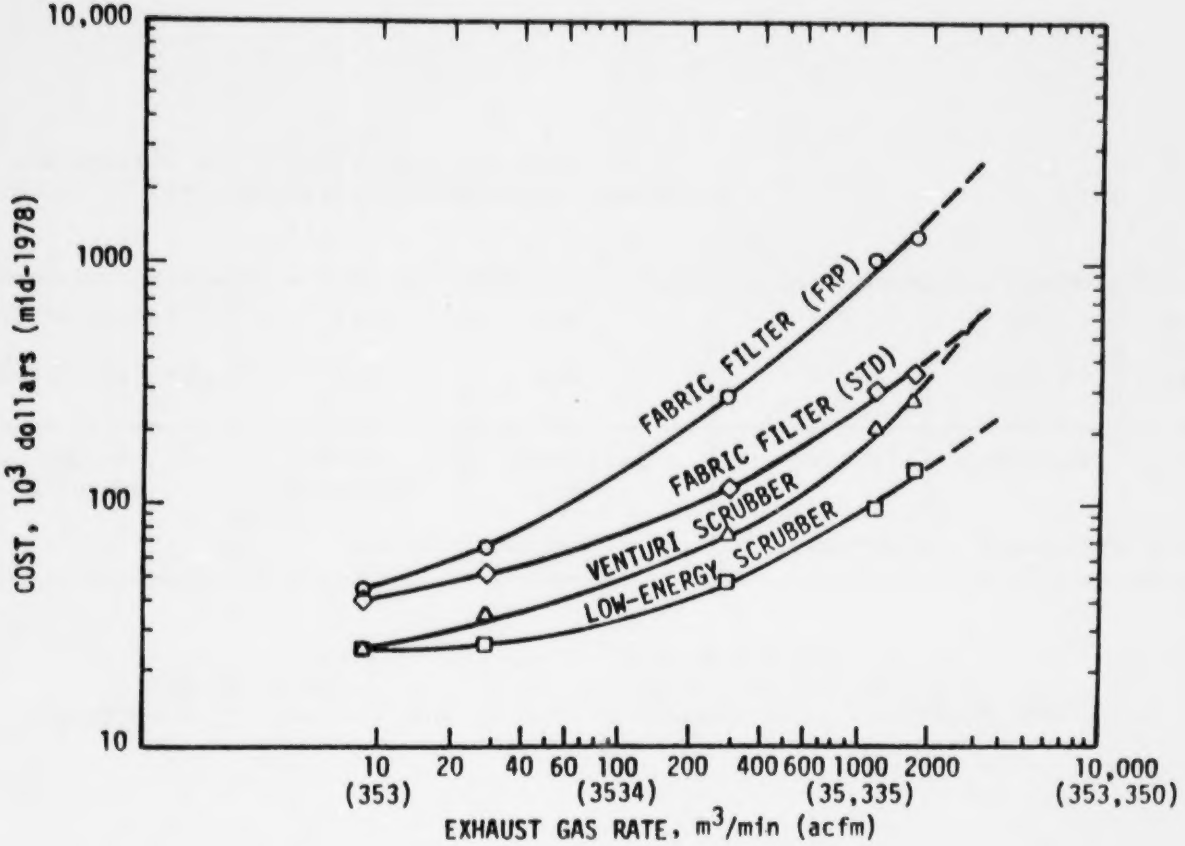

Figure 8-5. Investment costs for control alternatives used on ammonium sulfate dryers.

TABLE 8-42. CAPITAL AND ANNUAL OPERATING COST ESTIMATES FOR TWO 22.7-Mg/h (25 ton/h) AMMONIUM SULFATE DRYERS[a]
(thousands of mid-1978 dollars)

Type of dryer	Capital costs		Annualized operating costs		
	Equipment only	Total installed	Direct	Indirect	Total
Fluidized bed[b]	275	566	171	120	291
Rotary drum	195	420	168	93	261

[a] Used in the caprolactam byproduct industry.
[b] Consisting of a dryer and a cooler.

more than that of a rotary drum dryer. Most of the operating costs and characteristics of the two dryers are comparable but, because of a higher gas flow rate and pressure drop, the horsepower requirements for a fluidized-bed dryer are higher than for a rotary dryer. The fluidized-bed dryer, however, has the advantage of sweeping fines out of the bed; it in effect classifies the product and thereby improves product quality.

8.2.1.3 Incremental Cost of Control Systems--

Control systems designed to meet the emission limitations of a State Implementation Plan (SIP) are generally less costly than those designed to meet the more stringent limitations of the Option II. (Typical SIP's for ammonium sulfate facilities apply relatively lenient process weight regulations to particulate emissions). The low-energy scrubber is the baseline control device needed to meet SIP regulations. Incremental cost, therefore, is considered here to be the difference between the cost of a fabric filter or venturi scrubber and the cost of a low-energy scrubber.

Incremental capital and annualized control costs for each of the major segments of the ammonium sulfate industry are presented in Tables 8-43 through 8-46. Generally, the fabric filter and venturi scrubber cost more than a low-energy scrubber. The annualized cost of a venturi scrubber at low exhaust gas rates, however, is slightly less than the annualized cost of a low-energy scrubber because of the high market value of the ammonium sulfate recovered. Figures 8-6 through 8-8 show cost curves for the incremental costs of control equipment in each segment of the ammonium sulfate industry.

8.2.1.4 Cost-Effectiveness of Control Systems--

Tables 8-47 through 8-50 compare the cost-effectiveness of fabric filters and venturi scrubbers with that of low-energy wet scrubbers in the same applications. Each table shows the difference in the annualized costs of removing a standard amount of pollutant with a fabric filter or venturi scrubber and removing the same amount of pollutant with a low-energy scrubber. These costs, which are given for each segment of the industry, take into account the direct operating costs, capital charges, and credits for dust recovery. Figures 8-9 through 8-11 indicate the cost-effectiveness of each control system at various dryer exhaust gas rates.

TABLE 8-43. INCREMENTAL COST OF PARTICULATE CONTROL TO MEET OPTION II: CAPROLACTAM BYPRODUCT INDUSTRY; 27.2-Mg/h (30-ton/h) DRYERS[a]

System	Combined exhaust rate		Incremental installed capital cost, \$1000[c]	Incremental annualized costs[b]			
	m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Fabric filter (FRP)	3000	106,000	2052	5.7	389.2	(10.4)[d]	384.5
Fabric filter (STD)	3000	106,000	442	5.7	88.7	(10.4)	84.0
Venturi scrubber	3000	106,000	252	101.6	47.4	(10.4)	138.6

[a] Incremental cost of control system over that of low-energy scrubbers, which meet SIP but not Option II emission limits.

[b] Operating factor: 8400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-44. INCREMENTAL COST OF CONTROL TO MEET OPTION II: CAPROLACTAM BYPRODUCT INDUSTRY; 22.7-Mg/h (25-ton/h) DRYERS[a]

System	Combined exhaust rate		Incremental installed capital cost, \$1000[c]	Incremental annualized costs[b]			
	m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Fabric filter (FRP)	143	5,058	144	(0.8)[d]	27.1	(14.2)	12.1
	588	20,766	490	0.3	91.7	(13.7)	78.3
	1469	15,916	1220	4.6	223.0	(12.8)	214.8
	2368	83,766	1924	18.5	354.4	(11.9)	361.0
Fabric filter (STD)	143	5,058	83	(0.8)	15.7	(14.2)	0.7
	588	20,766	150	0.3	28.2	(13.6)	14.9
	1469	51,916	250	4.6	47.5	(12.8)	39.3
	2368	83,766	354	18.5	72.3	(11.9)	78.9
Venturi scrubber	143	5,058	28	3.4	5.5	(14.2)	(5.3)
	558	20,766	64	15.4	12.3	(13.7)	14.0
	1469	51,916	126	41.0	23.9	(12.8)	52.1
	2368	83,766	224	69.3	42.3	(11.9)	99.7

[a] Incremental cost of control system over that of low-energy scrubbers, which meet SIP but not Option II emission limits.

[b] Based on an operating factor of 8400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-45. INCREMENTAL COST OF PARTICULATE CONTROL TO MEET OPTION II: PRIME INDUSTRY[a]

System	Exhaust rate		Incremental installed capital cost, \$1000[c]	Incremental annualized costs[b]			
	m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Fabric filter (FRP)	44.1	558	52	(1.1)[d]	9.0	(3.2)	4.7
	176.3	6,230	160	(0.4)	29.6	(3.1)	26.1
	440.8	15,575	377	1.0	70.3	(3.0)	68.3
	705.2	24,920	581	2.2	108.6	(2.8)	108.0
Fabric filter (STD)	44.1	558	33	(1.1)	5.5	(3.2)	1.2
	176.3	6,230	60	(0.4)	10.9	(3.1)	7.4
	440.8	15,575	92	1.0	17.2	(3.0)	15.2
	705.2	24,920	121	2.2	22.8	(2.8)	22.2
Venturi scrubber	44.1	558	11	0.7	2.1	(3.2)	(0.4)
	176.3	6,230	23	2.7	4.5	(3.1)	4.1
	440.8	15,575	42	7.6	8.0	(3.0)	12.6
	705.2	24,920	61	12.5	11.5	(2.8)	21.2

[a] Incremental cost of control system over that of a low-energy scrubber, which meets SIP but not Option II emission limits.

[b] Based on an operating factor of 5400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-46. INCREMENTAL COST OF PARTICULATE CONTROL TO MEET OPTION II: COKE OVEN BYPRODUCT INDUSTRY[a]

System	Exhaust rate		Incremental installed capital cost, \$1000[c]	Incremental annualized costs[b]			
	m^3/min	acfm		Direct, \$1000[c]	Capital charges, \$1000[c]	Recovery credits, \$1000[c]	Net total, \$1000[c]
Fabric filter (FRP)	8.8	312	16	(0.6)[d]	2.8	(1.5)	0.7
	35.3	1246	42	(1.0)	7.6	(1.5)	5.1
	88.2	3115	85	(0.2)	15.5	(1.4)	13.9
	134.4	4784	125	(0.1)	23.0	(1.4)	21.5
Fabric filter (STD)	8.8	312	15	(0.6)	2.6	(1.5)	0.5
	35.3	1246	29	(1.0)	5.1	(1.5)	2.6
	88.2	3115	44	(0.2)	7.9	(1.4)	6.3
	134.4	4784	53	(0.1)	9.6	(1.4)	8.1
Venturi scrubber	8.8	312	4	0.2	0.8	(1.5)	(0.5)
	35.3	1264	9	0.7	1.8	(1.5)	1.0
	88.2	3115	15	1.9	2.9	(1.4)	3.4
	134.4	4784	20	3.0	3.9	(1.4)	5.5

[a] Incremental cost of control system over that of a low-energy scrubber, which meets SIP but not Option II emission limits.

[b] Based on an operating factor of 7400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

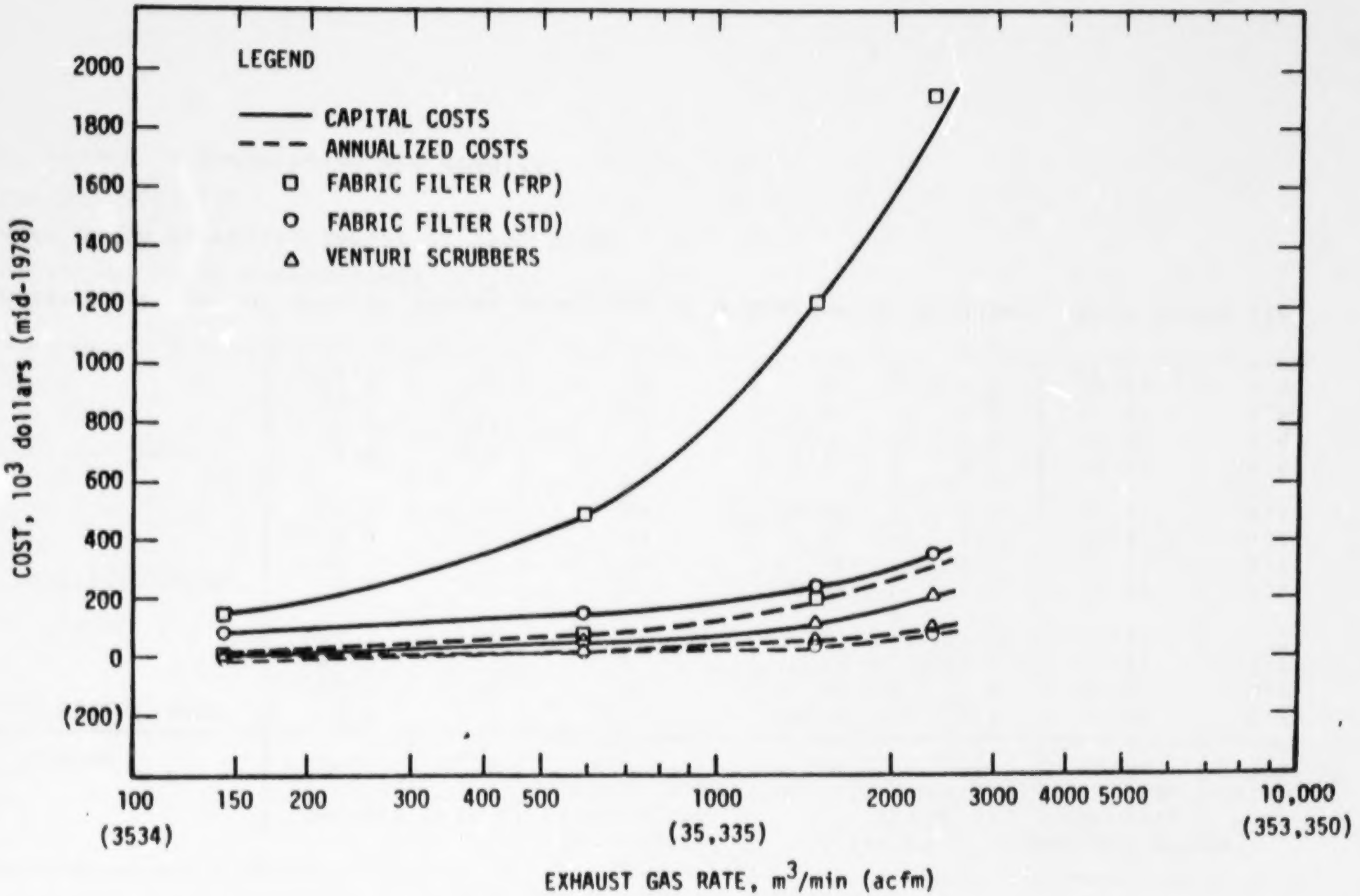

Figure 8-6. Incremental cost of control alternatives for two 22.7-Mg/h (25 ton/h) ammonium sulfate dryers in caprolactam byproduct industry.

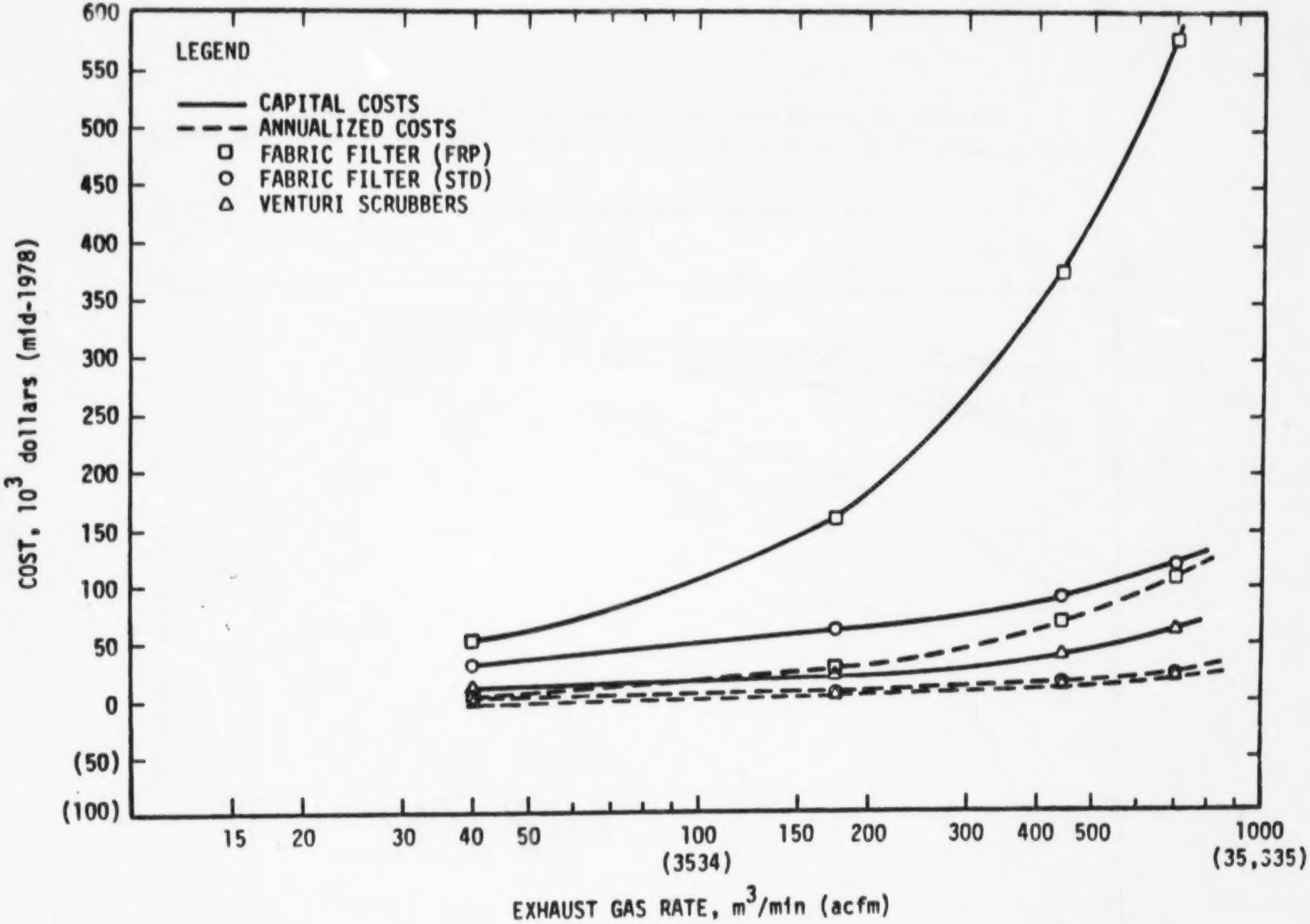

Figure 8-7. Incremental cost of control alternatives for a 13.6-Mg/h (15 ton/h) ammonium sulfate dryer in prime industry.

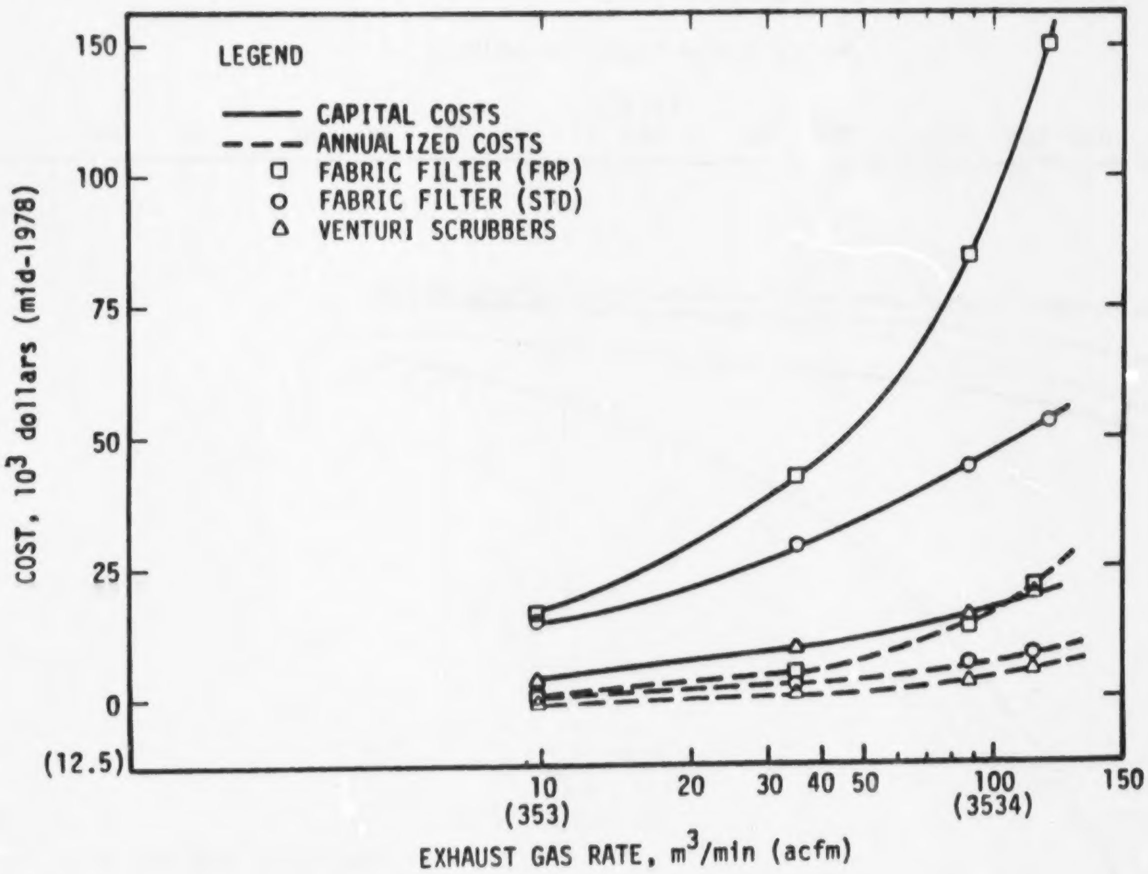

Figure 8-8. Incremental cost of control alternatives for a 2.7-Mg/h (3 ton/h) ammonium sulfate dryer in the coke oven byproduct industry.

TABLE 8-47. COST-EFFECTIVENESS OF ADDITIONAL PARTICULATE CONTROL TO MEET OPTION II: CAPROLACTAM BYPRODUCT INDUSTRY; 27.2 Mg-h (30-ton/h) DRYERS

System	Exhaust rate		Incremental pollutant collected[a]		Incremental annualized cost,[b] $1000[c]	Cost-effectiveness	
	m^3/min	acfm	Mg/yr	tons/yr		$/Mg[c]	$/ton[c]
Fabric filter (FRP)	3000	106,000	249	275	384.5	1542	1399
Fabric filter (STD)	3000	106,000	249	275	84.0	337	306
Venturi scrubber	3000	106,000	249	275	137.7	552	501

[a] In addition to the pollutant collected by low-energy scrubbers, which meet SIP but not Option II emission limits.

[b] In addition to the cost of low-energy scrubbers; based on an operating factor of 8400 h/yr.

[c] Mid-1973 dollars.

TABLE 8-48. COST-EFFECTIVENESS OF ADDITIONAL PARTICULATE CONTROL TO MEET OPTION II: CAPROLACTAM BYPRODUCT INDUSTRY; 22.7-Mg/h (25-ton/h) DRYERS

System	Exhaust rate		Incremental pollutant collected[a]		Incremental annualized cost,[b] $1000[c]	Cost-effectiveness	
	m^3/min	acfm	Mg/yr	tons/yr		$/Mg[c]	$/ton[c]
Fabric filter (FRP)	143	5,058	268	296	12.1	45	41
	588	20,766	258	284	78.3	303	276
	1469	51,916	242	267	214.8	888	804
	2368	83,766	225	248	361.0	1604	1456
Fabric filter (STD)	143	5,058	268	296	0.7	3	2
	588	20,766	258	284	14.9	58	52
	1469	51,916	242	267	39.3	162	147
	2368	83,766	225	248	78.9	351	318
Venturi scrubber	141	5,058	268	296	(5.3)[d]	(20)	(18)
	558	20,766	258	284	14.0	54	49
	1469	51,916	242	267	52.1	215	195
	2368	83,766	225	248	99.7	443	402

[a] In addition to pollutant collected by low-energy scrubbers, which meet SIP but not Option II emission limits.

[b] In addition to the cost of low-energy scrubbers; based on an operating factor of 8400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-49. COST-EFFECTIVENESS OF ADDITIONAL PARTICULATE CONTROL TO MEET OPTION II: PRIME INDUSTRY[a]

System	Exhaust rate		Incremental pollutant collected[a]		Incremental annualized cost,[b] $1000[c]	Cost-effectiveness	
	m^3/min	acfm	Mg/yr	tons/yr		$/Mg[c]	$/ton[c]
Fabric filter (FRP)	44.1	1,558	60.7	66.9	4.7	77	70
	176.3	6,230	59.4	65.5	26.1	439	398
	440.8	15,575	56.0	61.7	68.3	1220	1107
	705.2	24,920	53.4	58.9	108.0	2022	1834
Fabric filter (STD)	44.1	1,558	60.7	66.9	1.2	20	18
	176.3	6,230	59.4	65.5	7.4	125	113
	440.8	15,575	56.0	61.7	15.2	271	246
	705.2	24,920	53.4	58.9	22.2	416	377
Venturi scrubber	44.1	1,558	60.7	66.9	(0.4)[d]	(7)	(6)
	176.3	6,233	59.4	65.5	4.1	69	63
	440.8	15,575	56.0	61.7	12.6	225	204
	705.2	24,920	53.4	58.9	21.2	397	360

[a] In addition to pollutant collected by a low-energy scrubber, which meets SIP but not Option II emission limits.

[b] In addition to the cost of a low-energy scrubber based on an operating factor of 5400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

TABLE 8-50. COST-EFFECTIVENESS OF ADDITIONAL PARTICULATE CONTROL TO MEET OPTION II: COKE OVEN BYPRODUCT INDUSTRY

System	Exhaust rate		Incremental pollutant collected[a]		Incremental annualized cost,[b] $1000[c]	Cost-effectiveness	
	m^3/min	acfm	Mg/yr	tons/yr		$/Mg[c]	$/ton[c]
Fabric filter (FRP)	8.8	312	28.6	31.5	0.7	24	22
	35.3	1246	27.8	30.7	5.1	183	166
	88.2	3115	27.5	30.3	13.9	505	459
	134.4	4784	26.2	28.9	21.5	821	744
Fabric filter (STD)	8.8	312	28.6	31.5	0.5	17	16
	35.3	1246	27.8	30.7	2.6	94	85
	88.2	3115	27.5	30.3	6.3	229	208
	134.4	4784	26.2	28.9	8.1	309	280
Venturi scrubber	8.8	132	28.6	31.5	(0.5)[d]	(17)	(16)
	35.3	1246	27.8	30.7	1.0	36	33
	88.2	3115	27.5	30.3	3.4	124	112
	134.4	4784	26.2	28.9	5.5	210	190

[a] In addition to pollutant collected by a low-energy scrubber, which meets SIP but not Option II emission limits.

[b] In addition to the cost of a low-energy scrubber based on an operating factor of 7400 h/yr.

[c] Mid-1978 dollars.

[d] All values in parentheses are credits.

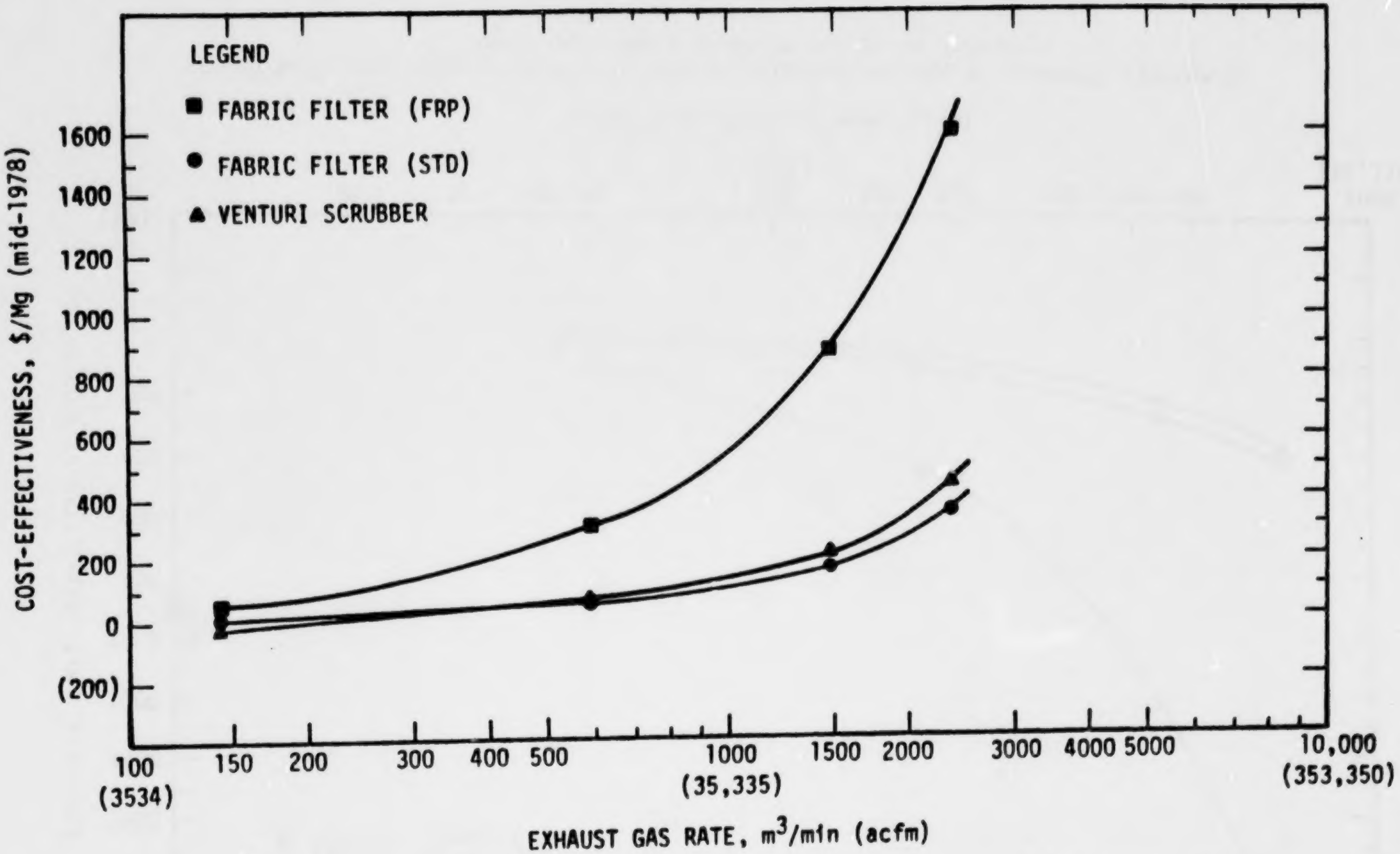

Figure 8-9. Cost-effectiveness of control alternatives for two 22.7-Mg/h (25-ton/h) ammonium sulfate dryers in the caprolactam industry.

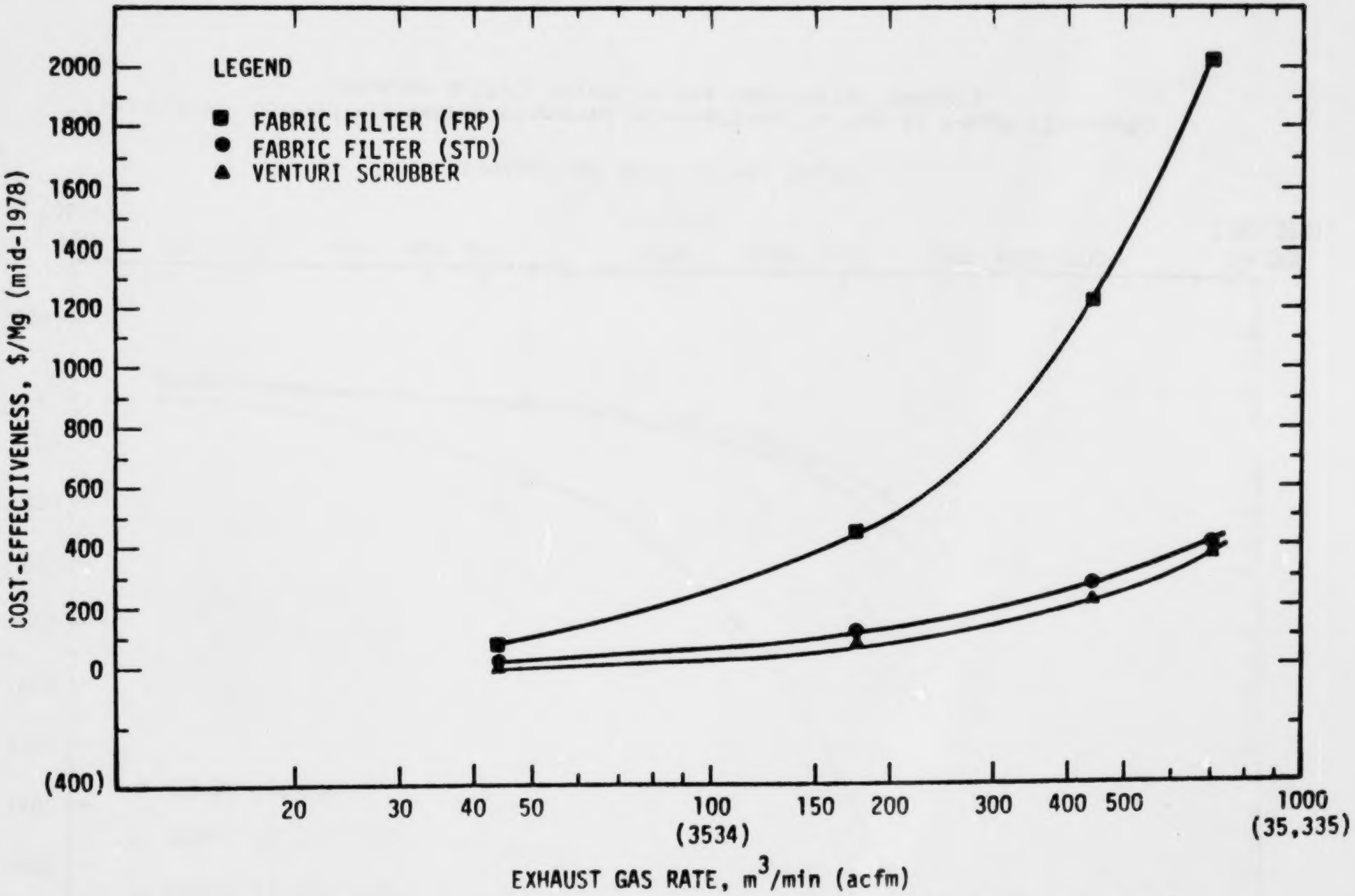

Figure 8-10. Cost-effectiveness of control alternatives for a 13.6-Mg/h (15-ton/h) ammonium sulfate dryer in the prime industry.

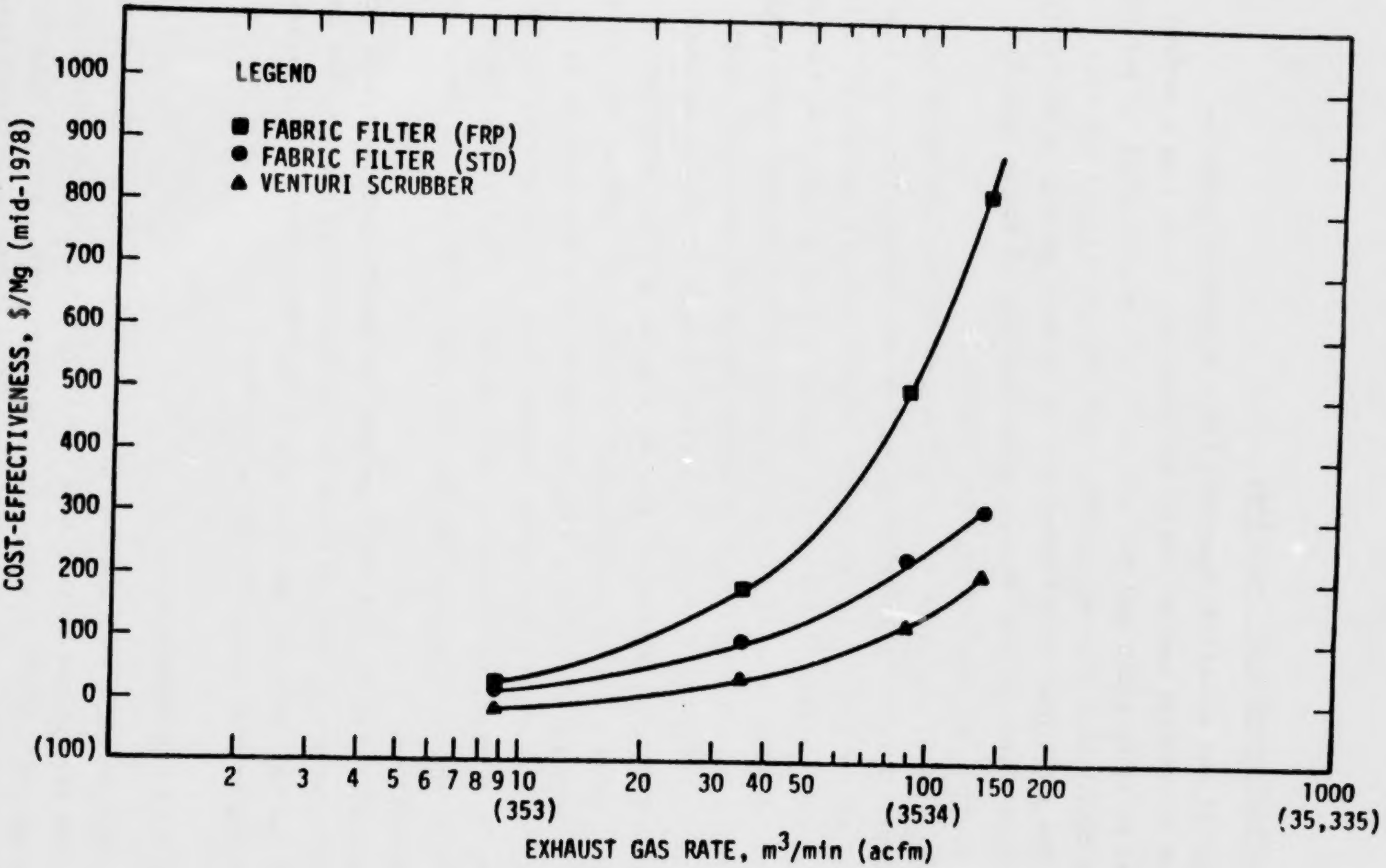

Figure 8-11. Cost-effectiveness of control alternatives for a 2.7-Mg/h (3-ton/h) ammonium sulfate dryer in the coke oven byproduct industry.

8.2.2 Modified/Reconstructed Facilities

8.2.2.1 Capital and Annualized Operating Costs of Control Systems--

Because it requires special design modifications, installing a control system in an existing plant that has been modified, reconstructed, or expanded may be more costly than in a new facility with the same exhaust gas rate. Estimating the additional installation cost or retrofit penalty is difficult because of such plant-specific factors as availability of space, need for additional ducting, and engineering requirements.

Configuration of equipment in a plant determines the location of the control system. A retrofit installation may require long ducting runs from ground level to the control device, stack, and reprocessing equipment. Costs may increase considerably if the control equipment must be placed on the roof of a process building, thus requiring the addition of structural steel support. It is estimated that rooftop installation can double the structural costs. In addition, it is likely that premium wage rates in accordance with governmental regulations and/or union agreements will have to be paid for installation labor. Also, space restrictions and plant configuration problems may increase contractor's fees and engineering fees, estimated for a new facility at 15 percent and 10 percent of total costs, respectively. These charges may be 20 percent and 15 percent, respectively, for a retrofit installation. These fees also vary with the difficulty of the job, the risks involved, and prevailing economic conditions.

The annualized costs of control systems for modified/reconstructed facilities are calculated similarly to those for new facilities; however, the components of capital costs for modified plants (see Table 8-16) are approximately 20 percent higher than those for new facilities.

8.3 OTHER COST CONSIDERATIONS

This section deals with the cost of complying with various Federal regulations. The regulations concern water quality, prevention of significant deterioration (PSD) of air quality, solid waste disposal, and the hazards in working with ammonia and sulfuric acid determined by the Occupational Safety and Health Administration (OSHA).

8.3.1 Costs of Compliance with Water Quality Regulations

Facilities within the prime segment of the ammonium sulfate industry that discharge into surface waters are subject to the effluent limitations specified in National Pollutant Discharge Elimination System (NPDES) permits. Direct dischargers are required to comply with the effluent limitations based on best practicable technology (BPT) through July 1977 and best available technology (BAT) economically achievable by mid-1984. The current standard for both BPT and BAT prohibits the discharge of any process waste water pollutants into navigable waters. Prime facilities already discharging into publicly owned treatment works must comply with Federal pretreatment standards.

New facilities discharging ammonium sulfate into surface waters are subject to NSPS, which are identical to BAT limitations. New plants discharging into publicly owned treatment facilities must meet Federal pretreatment standards more stringent than those for existing sources.

No known prime and caprolactam industries discharge effluents into sewage systems. The coke oven industry may discharge into sewage systems.[36]

8.3.2 Costs of Compliance with PSD Regulations

The 1977 amendments to the Clean Air Act include extensive provisions to prevent significant deterioration of air quality in regions where pollutant levels are already lower than those specified in ambient standards. The PSD regulations apply only to major stationary sources and specify the amount or "increment" of deterioration that the EPA will allow for a particular pollutant. The AS industry is subject to PSD requirements as it is included in the 28 listed categories of sources that emit or have the potential to emit 91 Mg (100 tons) per year or more of any pollutant. These include iron and steel mill plants, coke oven batteries, and chemical process plants. In addition, any source with the potential to emit 227 Mg (250 tons) per year is subject to the regulations.

All such major sources are required to install the best available control technology (BACT) for each pollutant exceeding the limit. In addition, the owner or operator of a proposed source or modification is required to demonstrate that allowable emission increases from the source will not cause a violation of the National Ambient Air Quality Standards. To comply with these requirements and obtain a construction permit, the owner or operator of a proposed new source must agree to conduct ambient air quality monitoring to the extent the EPA determines necessary. The owner or operator of the source is required to submit information regarding the design and layout of the source and an analysis of likely impairment to visibility, soils, and vegetation. PSD regulations also require modeling to assess the effects of emissions from a proposed new source.

The costs of complying with PSD regulations can vary from $3000 for operation of a single ambient air monitor to more than $100,000 for extensive modeling and testing.[37]

8.3.3 Costs of Compliance with Solid Waste Disposal Regulations

Generally, sludges and other solid wastes must be disposed of in a landfill. Such solids can be disposed of only in sanitary landfills approved by the State in accordance with guidelines set forth in the Resource Conservation and Recovery Act. Because all AS pollutant emissions recovered by the control systems during the manufacture of ammonium sulfate are reprocessed, no solid waste is generated.

8.3.4 Costs of Compliance with Occupational Safety and Health Administration (OSHA) Regulations

The cost of compliance with OSHA regulations for the prime segment of the ammonium sulfate industry is incurred principally in the storage and handling of pure ammonia and sulfuric acid. The anhydrous ammonia regulations specify the type and location of containers in which ammonia may be stored, hose requirements, safety-relief devices, and protective equipment for employees. Protective equipment includes readily accessible face masks and shower facilities. Employee exposure to sulfuric acid is limited to 1 mg/m^3 in any 8-hour work shift. Compliance with this limitation is achieved through appropriate administrative or engineering controls and, where necessary, protective equipment and other measures.[38] In addition, ammonium sulfate facilities are subject to the general industrial health and safety standards promulgated by OSHA.

The cost of complying with OSHA regulations depends on such variables as the type and configuration of process equipment and special design considerations. Many OSHA requirements for the storage and handling of ammonia and sulfuric acid are already commonly practiced in the industry. Consequently, the additional costs incurred for compliance with OSHA regulations can only be broadly estimated to be in the order of magnitude of several thousand dollars. The costs incurred for compliance are small in relation to total plant costs.

8.4. Economic Impact Analysis

8.4.0. Introduction

The economic impact analysis is based on the synthetic, coke oven by-product and caprolactam by-product model plants presented in section 6.1. The analysis focuses upon worst-case model plants, that is, those plants likely to be most adversely affected by the regulatory options considered below. All other types of plants will be less adversely affected by the regulatory options than the worst-case facilities, and, as the estimated regulatory economic impacts for worst-case plants are very small, the economic impacts on other plants are likely to be negligible. Consequently, the additional information generated by a more extensive and resource intensive analysis would provide no useful additional information. Price and rate of return impacts associated with the regulatory options are calculated for the worst-case model plants and form the basis for the assessment of industry wide economic impacts. From an economic perspective, plants facing the highest incremental costs of complying with a regulation are the worst case plants, that is, the AS plants with the highest exhaust rates. Plants with smaller dryer exhaust rates encounter smaller incremental costs of control and will be less adversely affected by a regulator alternative.

8.4.1. Control Options

Two control options are being considered by EPA:

Option 1. New modified and reconstructed plants must comply with emissions limits typical of existing SIP regulations.

This regulatory option could be achieved by the installation of low energy scrubbers on the dryers. Under this regulation, no plant would incur any incremental costs* and consequently no economic impacts would result from its implementation.

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*Incremental costs, in this situation, are those additional costs a firm incurs in meeting Option II that it would not incur in meeting Option I, existing SIP emission limits.

Option II. New, modified and reconstructed plants must comply with an emissions limits of 0.150 kilograms per megagram of AS production.

Two control devices can be used by each of the three major types of AS plants to attain compliance with Option II: (1) medium energy venturi scrubbers, and (2) fabric filters. Plants utilizing either of these control technologies will incur incremental costs; that is, costs that would not be encountered by complying with existing SIP's. Consequently, economic impacts would result from the implementation of regulatory Option II.

8.4.2. Economic Methodology

8.4.2.1. Regulatory Scenarios

Economic impacts are estimated only for regulatory Option II as no incremental costs would be incurred by firms complying with regulatory Option I. However, as was noted above, affected facilities may comply with regulatory Option II by installing venturi scrubbers or fabric filters. Venturi scrubbers and fabric filter baghouses may be constructed of fiberglass reinforced plastic (FRP), stainless steel, lined carbon steel, or carbon steel (STD). (FRP has the highest acidic corrosion resistance and STD has the least resistance.) Economic impacts, however, are estimated only for FRP venturi scrubbers, FPP fabric filters, and STD fabric filters. Economic impacts are estimated under two alternative assumptions about firm pricing behavior: (1) full cost absorption and (2) full cost pricing. Combining the two control technologies with the two alternative pricing models yields six regulatory scenarios:

	Control Technology	Pricing Policy
Scenario 1	Venturi Scrubbers	Full Cost Absorption
Scenario 2	Venturi Scrubbers	Full Cost Pricing
Scenario 3	STD Fabric Filter	Full Cost Absorption
Scenario 4	STD Fabric Filter	Full Cost Pricing
Scenario 5	FRP Fabric Filter	Full Cost Absorption
Scenario 6	FRP Fabric Filter	Full Cost Pricing

Under full cost absorption an affected firm bears the full incremental costs of environmental controls, accepting a lower rate of return on its capital investment. Under full cost pricing the firm adjusts product prices so as to maintain its current after-tax rate of return on capital investment.

The alternative assumptions about firm pricing behavior are associated with different market conditions in the affected industry. In both cases, firms are assumed to have no monopsony power in resource markets. Thus, they cannot pass back cost increases to resource suppliers. However, in the cost absorption case the domestic industry as a whole is assumed to be a price taker, unable to affect the market price of its product either because of the existence of close product substitutes, or because of strong international competition in domestic and foreign markets. Full cost pricing will take place if the industry produces a commodity for which no substitutes exist or if it is a constant cost industry.*

In fact, the U.S. ammonium sulfate industry faces strong competition from substitute products such as urea, ammonium nitrate and anhydrous ammonia in domestic markets. In overseas markets it faces competitition from foreign producers of AS. Consequently, the full cost absorption scenarios evaluated below provide more representative estimates of the economic impacts resulting from implementing regulatory Option II than do the full cost pricing scenarios. Full cost pricing scenarios are only considered in order to provide a maximum estimate of the possible inflationary consequences of such a regulation.

8.4.2.2. Economic Conditions

The impacts associated with each of the six regulatory scenarios are calculated under two different sets of economic conditions. Both sets of conditions assume that all control equipment has a twenty-year life; the price of AS received by producers is $66.14 per metric ton and the tax rate is 52 percent. However, under the first set of conditions, firms are assumed to have a target rate of return on investment of 6 percent. Under the second set, the target rate of return is assumed to be 15 percent. None of the firms for which financial data was available received an after tax return on equity of less than 11.3 percent or more than 14.29 percent in 1977 (see table 8-11). Hence the alternative assumptions about the target rate of return for affected facilities cover the range of actual rates of return on equity experienced by firms producing AS.

A lower bound of 6 percent was selected for the interest rate variable to reflect the general economic conditions facing the iron and steel industry, of which coke oven by-products plants are a part. The iron and steel industry experienced an average after-tax rate of return on equity of only 7.4 percent between 1968 and 1977 and in four of those years the after-tax rate of return was less than 6 percent.[33]

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*In a constant-cost industry, as industry output increases unit costs remain constant as long as resource prices, labor productivity and the industry technology remain the same.

8.4.2.3. Estimation of Regulatory Price Impacts Under Full Cost Pricing

Under full cost pricing, the firm is assumed to respond to cost increases by adjusting product price to maintain a target rate of return on investment. The required price change (ΔP) may be calculated using the following equation:

$$\Delta P = \frac{\Delta\ TOC + r \times \Delta K/(1-t)}{Q}$$

where ΔP = required product price change

ΔTOC = annual total operating costs of the control equipment

ΔK = total acquisition and installation costs of the control equipment

Q = annual plant output

r = target rate of return

t = tax rate

Note that total annual operating costs (ΔTOC) include an allowance for depreciation of the equipment in addition to regular maintenance and operating costs. Annual depreciation is estimated to be 5 percent of the acquisition and installation costs of the control equipment.*

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*The depreciation estimate is based on the assumption of straight line depreciation of the equipment over its twenty year life. plants, capital expenditures and employment in the AS industry. In addition, interindustry and macroeconomic impacts are discussed.

8.4.2.4. Estimation of Rate of Return Impacts Under Full Cost Absorption

Under full cost absorption, an increase in plant costs of production results in a lower rate of return on investment for the firm as it cannot pass cost increases on to consumers in the form of higher product prices. The impact on the plant's rate of return on investment is given by the following equation:

$$\Delta r = \frac{(t-1)\,\Delta TOC - r\,\Delta K}{K + \Delta K}$$

where Δr denotes the change in the rate of return in investment, and K denotes the pre-regulation level of capital investment (measured in dollars). Note that K represents the pre-regulation level of capital investment in the affected facility.

8.4.2.5. Other Economic Impacts

The price and rate of return impacts estimated by the above techniques are used to make a quantitative assessment of the probable impact of regulatory Option II on industry growth, new plant openings, reconstructions and modifications of existing facilities, annualized costs of control and investment levels. These data are used to assess the extent of interindustry and macroeconomic impacts associated with Option II.

8.4.2.6. Data

In addition to information about target rates of return and the tax rate, the estimation of price and rate of return impacts requires data on the following variables for each affected facility: (1) total acquisition and installation costs of the control equipment (ΔK), (2) total annual operating costs of the control equipment (ΔTOC), and (3) the pre-regulation capital stock (K). Data on ΔK and ΔTOC were obtained from section 8.2. Estimates of pre-regulation capital investment for the synthetic, AS coke oven by-product and caprolactam model plants are presented in table 8-51.

Table 8-51 Capital Investment in the Ammonium Sulfate Industry (December 1978)

Process	Model Plant Capacity (Mg)	Pre-Regulation Capital ($\$10^6$)
Synthetic	73,483	1.526
Coke Oven	19,958	0.647
Caprolactam	381,022	21.756

SOURCE: Research Triangle Institute

The estimates of pre-regulation capital investment levels were obtained in the following ways:

Synthetic Product. Data on the value of capital equipment tied up in a synthetic AS plant with a capacity of 63.5 Gg in 1973 are presented in David et.al.[34] These data were updated to December 1978 using the Bureau of Labor Statistics (BLS) machinery and equipment price index.[35] This figure was then multiplied by a factor of 1.157 (=73.483Gg/63.5Gg) to obtain an estimate of the level of capital investment required for a synthetic AS plant with a capacity of 73.483Gg.

Coke Oven By-product Plant. A capital output coefficient for the iron and steel industry was calculated by dividing total industry assets by the total value of industry shipments for 1977.[36] This coefficient was updated to December 1978 using the BLS machinery and equipment and iron and steel price indices. The capital-output coefficient was then multiplied by the value of the shipments of the plant, estimated to be $1.32 million, to obtain an estimate of total capital investment for the coke oven by-product model plant.*

Caprolactam By-Product. A capital-output coefficient for the organic chemical industry was obtained by dividing 1976 total industry assets by total value of shipments for S.I.C. code industry 2869, Industrial Organic Chemicals.[37] The capital-output ratio was updated to December 1978 using the BLS price indices for machinery and equipment and industrial chemicals. The updated capital output ratio was then multiplied by the value of AS shipments from the model plant, estimated to be $25.2 million, to obtain the estimate of total capital investment for the caprolactam model plant.

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*Plant value of shipments is obtained by multiplying plant capacity by product price, where the price of AS is assumed to be $66.14 per metric to

8.4.3. Economic Impacts

8.4.3.1. Summary

Regulatory options I and II are likely to have minimal impacts on the ammonium sulfate industry itself. New plant construction and modifications or reconstructions of existing facilities that would have taken place in the absence of an NSPS will almost certainly still be carred out. Further, price, rate or return, investment and employment impacts will probably be negligible. In addition, it should be noted that the AS industry may be beneficially affected by forthcoming NSPS's for urea and ammonium nitrate.

8.4.3.2. Rate of Return Impacts

Estimates of the impacts on model plant ROI's of regulatory Option II are presented in table 8-52. These results were calculated on the assumption that firms absorb all the control costs and do not increase product prices. For synthetic and coke oven by-product plants, the impacts associated with complying with regulatory Option II are smallest when Venturi scrubbers are installed. For caprolactam plants, the impacts are smallest when compliance is achieved by installing STD fabric filbers. However, based on operating experience and nearly equal overall costs, it is most realistic that FRP venturi scrubbers will be installed to meet a stringent standard.* [38,39] Plants

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*Capital costs of FRP venturi scrubbers are less than those of STD fabric filters and annualized cost of FRP venturis are only 2.4 percent greater. Venturi scrubbers are also much more compatible and complimentary with the AS process. AS feed streams are used as a scrubbing liquor and are easily recycled to the process without addition of excess water. The dry collected AS would require reslurry prior to being recycled to the process. Dry collection is also suseptible to condensation problems and STD fabric filters, due to corrosion rate, have a much shorter expected life than the FRP constructed control devices. (See table 8-38 and Chapters 3 and 4)

Table 8-52 Impact on Model Plant Rates of Return of Regulatory Options under Full Cost Absorption

Model Plant	Change in Rate of Return (percentage points)					
	Venturi Scrubbers (FRP)		Fabric Filters (STD)		Fabric Filters (FRP)	
	(r^*=6%)	(r=15%)	(r=6%)	(r=15%)	(r=6%)	(r=15%)
Synthetic	-0.68	-1.05	-0.62	-1.33	-2.93	-6.36
Coke Oven By-Product	-0.37	-0.65	-0.51	-1.25	-1.39	-3.13
Caprolactam By-Product	-0.29	-0.40	-0.16	-0.35	-0.75	-1.60

*r denotes the initial rate of return

Source: Research Triangle Institute.

earning a low initial ROI (6 percent) will experience decreases in their ROI's of between 0.29 (for caprolactam) and 0.68 (for synthetic) percentage points. These are extremely small impacts and are unlikely to deter firms from carrying out their investment plans. If firms earn a higher initial ROI (15 percent) the percentage point impacts will be slightly larger, with decreases ranging from of 0.40 (caprolactam) to 1.05 (synthetic). However, these impacts are still small, and firms experiencing relatively high initial ROI's are also unlikely tc alter investment plans in the face of such changes. Further note that the smallest ROI impacts occur in the caprolactam sector where all future industry growth is likely to be concentrated.

8.4.3.3. Price Impacts

The potential price impacts associated with regulatory Option II, calculated under the assumption of full cost pricing, are presented in table 8-53. Price impacts vary directly with the level of the target ROI assumed for each plant. However, the price impacts of regulatory Option II are smallest for coke synthetic and coke over by-product plants if they install venturi scrubbers instead of fabric filters. Again, the smallest impacts are associated with the cheapest control technologies. Plants with a relatively low target ROI (6 percent) under full cost pricing will increase product prices by between 0.52 percent (caprolactam by-product) and 0.45 percent (synthetic). Plants with relatively high target ROI's (15 percent) will attempt to increase product prices by between 0.71 percent (caprolactam by-product) and 0.69 percent (synthetic). The above price increases are relatively small and if passed through by AS users to consumers would result in a negligible increase in the general rate of inflation. Such price increases, if implemented across the AS industry, might reduce AS consumption by between 0.99 and

Table 8-53 Impact on Product Price of Regulatory Options under Full-Cost Pricing

Model Plant	Percentage Change in Product Price					
	Venturi Scrubbers (FRP)		Fabric Filters (STD)		Fabric Filters (FRP)	
	(r^*=6%)	(r=15%)	(r=6%)	(r=15%)	(r=6%)	(r=15%)
Synthetic	0.45	0.69	0.40	0.87	1.92	4.16
Coke Oven By-Product	0.38	0.66	0.53	1.27	1.41	3.17
Caprolactam By-Product	0.52	0.71	0.29	0.62	1.35	2.87

*r denotes the target rate of return on investment.

Source: Research Triangle Institute.

2.07 percent below the 1985 levels.* Even if such consumption decreases occurred, there would be no significant impacts on the need for additional AS facilities as the construction of caprolactam by-product facilties (the sector in which growth will occur) is determined by growth in the demand for caprolactam rather than for AS. In fact, as was noted above, AS producers are more likely to absorb cost increases than to raise prices especially when the cost increases are small. Since the costs of regulatory Option II are very small (see section 8.4.5.6), actual price impacts are likely to be negligible. Consequently, output effects are also likely to be negligible.

8.4.3.4. Employment Impacts

Regulatory Option II is unlikely to have a measurable impact on employment. The additional labor required for operating the control devices required under Option II is less than one-tenth of a man year, and no more than seven control devices are likely to be installed during the five-year period following promulgation. As AS output is likely to be unaffected by the regulation, no employment effects will result from adjustments to industry production levels.

8.4.3.5. Investment Impacts

Data on the investment impacts associated with regulatory Option II are presented in table 8-54. Regulatory Option II is likely to have no impacts on either the construction of new facilities or the modification or reconstruction of existing

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*These estimates, based on the assumption that firms install venturi scrubbers, are obtained by multiplying the smallest own-price elasticity of demand estimate (2.60) presented in section 8.1.7 by the smallest estimated potential price increase (0.38 percent) and the largest own price elasticity of demand (2.78) presented in section 8.1.7. by the largest estimated potential price increase (0.71 percent).

Table 8-54 Investment Impacts

	Affected Plants	Incremental Plant Costs of Control (10^6 dollars)	Incremental Sector Costs of Control (10^6 dollars)
Synthetic	2	0.061	0.122
Caprolactam By-Product	3	0.252	0.756
Coke Oven By-Product	4	0.020	0.080
TOTAL	9	-	0.958

SOURCE: Research Triangle Institute

plants. Under baseline projections, three caprolactam plants will be required to install control devices. It is probable that each of these plants will choose to install (FRP) medium energy venturi scrubbers. The incremental capital cost of installing each control unit (assuming maximum gas flow rates) is $252,000. Thus, the total incremental capital cost of controls for the caprolactam sector will be 0.756 million. Four coke oven by-product manufacturers are also likely to install control equipment over the five year promulgation period. They are likely to install venturi scrubbers because, for coke oven plants, these devices are cheaper than fabric filters. The maximum incremental cost of each such scrubber for a model coke oven by-product plant is $20,000. Thus, the total incremental cost of controls for the coke oven by-product sector over the five year promulgation period will be $80,000. Two existing synthetic plants may also have to install controls. They are likely to install venturi scrubbers, because for coke oven plants, these devices are cheaper than fabric filters. The maximum incremental cost of each such scrubber for a model synthetic plant is $61,000. Thus, total incremental capital costs of controls for the synthetic sector will be $122,000. The maximum of the regulation total capital costs for the entire industry will, therefore, be $0.958 million. These costs are very small relative to the historic patterns of capital investment in the affected industries. Further, they represent less than one hundreth of one percent of the total value of projected AS output for 1985*. The industry is therefore unlikely to face problems in financing these additional capital expenditures.

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*AS output is projected to be 677 Gg in 1985 and, for this calculation, was valued at $66.14 per metric ton.

8.4.3.6. Total Annualized Costs of Control

Total incremental annualized costs of control are presented in table 8-55 and are based on data presented in section 8.2. A capital recovery factor of 0.16, based on the assumption of a 15 percent rate of interest and a twenty year life for the control equipment, was used to calculate annualized capital costs. Coke oven by-product and synthetic AS plants are assumed to install venturi scrubbers capable of dealing with the highest gas flow rates considered in section 8.2. Caprolactam plants are also assumed to install FRP venturi scrubbers. By the fifth year after promulgation, under Option II total industry annualized costs of control will be $480,200. The industry-wide price increase required to generate revenues of an equivelant amount would be miniscule, less than 0.01 percent in 1985.

8.4.3.7. Interindustry Impacts

Interindustry impacts will be negligible if control cost increases are absorbed by AS producers. If they are passed through to AS users in the form of higher prices then demand for other nitrogenous fertilizers may increase. However, because AS has such a small share of the total nitrogen fertilizer market, the increase in the demand for each of the other nitrogenous fertilizers would be quite small. In addition, under full cost pricing farmers would be faced with higher costs of production for agricultural output. However, the share of AS fertilizer costs in total agricultural production costs is very small (less than one percent). Consequently, any change in the cost of producing AS would have a minimal impact on costs of production in agriculture and on food prices.

Table 8-55 Incremental Annualized Costs of Control: 1985+
(10^3 dollars)

Industry Sector	Number of Affected Facilities	Plant* Annualized Capital Costs	Annualized Plant Operating Costs	Plant Total Annualized Costs	Sector Total Annualized Costs
Synthetic	2	9.7	11.5	21.2	42.4
Caprolactam By-Product	3**	40.3	97.4	139.6	415.8
Coke Oven By-Product	4	3.2	2.3	5.5	22.0
TOTAL	9	-	-	-	480.2

SOURCE: Research Triangle Institute

+Based on the installation of Venturi Scrubbers

*Annualized Capital Costs = Installed Capital Costs of Control Equipment x Capital Recovery Factor.

**Costs for each Caprolactam Facility are for Two Dryers.

8.5. Socio-Economic and Inflationary Impacts

The socio-economic impacts of regulatory Option II will be very small.

(1) Annualized Costs. In the fifth year following promulgation of regulatory Option II, annualized costs of compliance will be \$0.4775 million, well below the regulatory analysis criterion of \$100 million.

(2) Price Impacts. An industry wide price increase of less than one-hundreth of one percent is all that would be required to provide revenues to meet these costs. In addition, the most adversely affected plants would only have to increase product price by 0.71 percent. Potential price increases are therefore also well below the 5 percent criterion for a regulatory analysis.

(3) Demand for Scarce Materials. It is conceivable that an ammonium sulfate regulation could increase demand for urea, one of the materials specified in the Federal Register as of special importance. However, any possible increase in the demand for urea which is likely to be considerably less than one percent, well below the 3 percent criterion outlined in the Federal Register.[40]

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9. RATIONALE FOR THE PROPOSED STANDARD

9.1 SELECTION OF SOURCE FOR CONTROL

The ammonium sulfate (AS) industry is a significant contributor to nationwide emissions of particulate matter. The Priority List (40 CFR 60.16, 44 FR 49222, August 21, 1979) identifies various sources of emissions on a nationwide basis in terms of quantities of emissions from source categories, the mobility and competitive nature of each source category, and the extent to which each pollutant endangers health and welfare. The Priority List reflects the Administrator's determination that emissions from the listed source categories contribute significantly to air pollution and is intended to identify major source categories for which standards of performance are to be promulgated. The ammonium sulfate manufacturing industry is listed among those source categories for which new source performance standards (NSPS) must be promulgated.

AS has been an important nitrogen fertilizer for many years. Its early rise to importance as a fertilizer evolved from its availability as a by-product from basic industries such as steel manufacturing and petroleum refining. By-product generation has continued to dominate the AS production industry. In fact, by-product AS from the caprolactam segment of the synthetic fibers industry is now the single largest source, accounting for more than 50 percent of AS production.

Production of AS as a by-product also ensures that it will continue as an important source of nitrogen fertilizer in the United States. This is illustrated by the fact that, in response to an increase in demand, caprolactam production is expected to increase at compounded annual growth rates of up to 7 percent through the year 1985; and for every megagram of caprolactam produced, 2.5 to 4.5 megagrams of AS are produced as a by-product.

Over 90 percent of AS is generated from three types of plants: synthetic, caprolactam by-product, and coke oven by-product. Investigation has shown that all growth in the AS industry will be within these industry sectors. Synthetic AS is produced by the direct combination of ammonia and sulfuric acid. Caprolactam AS is produced as a by-product from streams generated during caprolactam manufacture. Ammonia recovered from coke oven off gas is reacted with sulfuric acid to produce coke oven AS. These three major segments of the AS industry would be regulated by the proposed new source performance standard.

9.2 SELECTION OF POLLUTANTS

Study of the AS industry has shown that ammonium sulfate emissions are the principal pollutant emitted to the atmosphere from AS plants. At operating temperatures, the AS emissions occur as solid particulate matter, a "criteria" pollutant for which national ambient air quality standards have been promulgated. Studies have been conducted to evaluate the influence of AS as a co-factor in carcinogenesis and to determine the effects of AS upon human cardiopulmonary function. Results appear inconclusive as to the deleteriousness of AS as an air pollutant in itself.[1,2]

Currently a variety of wet collection systems are employed to control AS particulate emissions to levels of compliance with State and local air pollution regulations, a reduction of 97 to 98 percent. Existing State Implementation Plan (SIP) regulations vary from a low of 0.71 kilogram to a high of 1.3 kilograms of particulate per megagram of AS production. However, by the year 1985 new, modified, and reconstructed AS manufacturing dryers would cause annual nationwide particulate emissions to increase by about 670 Mg/year (737 tons/year) with emissions controlled to the level of a typical SIP regulation. (Estimate based on the growth rate demonstrated over the past decade.)

Hydrocarbon (HC) emissions are also emitted from process dryers at caprolactam by-product AS plants. Test data indicate that the HC emissions are largely in the vapor phase and at least two orders of magnitude lower than AS particulate emissions (110 kg/Mg for particulate matter versus 0.78 kg/Mg for the HC emissions). In addition, current particulate control systems (wet collectors) have demonstrated an 88 percent removal efficiency of the uncontrolled caprolactam HC emissions. At this control level, new, modified, and reconstructed caprolactam AS plants would add only about 76 Mg per year to nationwide HC emissions by 1985. Therefore, the only pollutant recommended for control by the proposed standards is particulate matter.

9.3 SELECTION OF THE AFFECTED FACILITY

Ammonium sulfate crystals are formed by continuously circulating a mother liquor through a crystallizer. When optimum crystal size is achieved, precipitated crystals are separated from the mother liquor (dewatered), usually by centrifuges. Following dewatering, the crystals are dried and screened to product specifications.

On-site inspection of AS plants reveals that nearly all of the particulate matter emitted to the atmosphere from AS manufacturing plants is in the gaseous exhaust streams from the process dryers. Other plant processes such as crystallization, dewatering, screening, and materials handling are not, in the opinion of EPA, significant emission sources.

AS dryers can be either of the fluidized bed (FB) or rotary drum type. All FB units found in the industry are heated continuously with steam-heated air. The rotary units are either direct-fired or steam heated. Based on data obtained from plant visits, air flow rates for the AS dryers at caprolactam plants range from 560 scm/Mg of product to 3,200 scm/Mg of product. The lower value represents direct-fired rotary drum drying units and the higher value represents fluidized bed drying units using steam-heated air. At synthetic plants, air flow rates range from 360 scm/Mg to 770 scm/Mg of product. All drying units at synthetic plants are of the rotary drum type; however, both direct-fired and steam-heated air are used as methods of dryer heating.

One consequence of the wide range of gas flow rates for the differing drying systems is that particulate emission rates, which are directly related to the gas-to-product ratio,* also vary considerably for each drying unit involved. Emission test results using EPA Method 5 at typical facilities are presented in Table 9-1.

Since the process dryer is the only significant source of AS particulate emissions, the AS manufacturing industry can be effectively controlled by specifying emission limitations for the process dryer. Therefore, the AS dryer has been selected as the affected facility for which particulate matter regulations are proposed.

9.4 SELECTION OF THE FORMAT OF THE RECOMMENDED STANDARDS

A mass per unit-time performance standard and such non-performance type standards as design, equipment, work practice, and operational standards were initially considered but were later judged as inappropriate for application to the AS industry. A standard based on mass per unit time (e.g., kg/hr) would require that a relationship be constructed showing how the allowable mass rate of emissions would vary with both production and time. Such a relationship could not be determined without extensive source tests performed at great expense.

Section 111(h) of the Clean Air Act establishes a presumption against design, equipment, work practice, and operational standards. For example, a standard based on a specific type of drying equipment without add-on controls or a standard limiting the dryer air flow rate cannot be promulgated unless a standard of performance is not feasible. Performance standards for control of AS dryer particulate emissions have been determined as practical and feasible; therefore, design, equipment, work practice, or operational standards were not considered as regulatory options.

The point should be noted, however, that uncontrolled emissions from all known dryers are too great to comply with existing state

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*Gas-to-product ratio is defined as the volume of dryer exhaust gas per unit of production, e.g., dry standard cubic meters per megagram of ammonium sulfate produced.

Table 1. SUMMARY OF UNCONTROLLED AS EMISSION DATA -- EPA EMISSION TESTS ON AS DRYERS

Plant	Dryer Type	Average Uncontrolled AS Emissions			
		gm/dscm	(gr/dscf)	kg/Mg	(lb/ton)
A	Rotary Drum	4.38	(1.93)	0.41	(0.82)
B	Fluidized Bed	39.0	(17.2)	110.	(221.)
C	Rotary Drum	8.87	(3.91)	3.46	(6.92)
D	Rotary Drum	98.3	(43.2)	77.	(153.0)

regulations even at the lowest air flow rates. It therefore would be impractical to consider a standard solely on the process equipment type or to limit emissions by specifying the air flow.

Two additional formats for the proposed standard were also considered: mass standards, which limit emissions per unit of feed to the AS dryer or per unit of AS processed by the dryer; and concentration standards, which limit emissions per unit volume of exhaust gases discharged to the atmosphere.

Mass standards, expressed as allowable emissions per unit of production, relate directly to the quantity of particulate matter discharged to the atmosphere. They regulate emissions based on units of input or output, thereby denying any dilution advantage. Mass standards allow for variation in process techniques such as decreasing the air flow rate through the dryer. A primary disadvantage of mass standards, as compared to concentration standards, is that their enforcement may be more time consuming and therefore more costly. The more numerous measurements and calculations required also increase the opportunities for error. Determining mass emissions requires the development of a material balance on process data concerning the operation of the plant, whether it be input flow rates or production flow rates. The need for such a material balance is particularly relevant in the case of AS plants. The determination of throughput in the affected facility, the AS dryer, is seldom direct. None of the plants investigated during development of the proposed standards made direct measurement of the dryer input or output. Process weights were determined indirectly through monitoring of input stream feed rates.

In general, enforcement of concentration standards requires a minimum of data and information, thereby decreasing the costs of enforcement and reducing the chances of error. Furthermore, vendors of emission control equipment usually guarantee equipment performance in terms of the pollutant concentration in the discharge gas stream. Although in the AS industry enforcement of concentration standards may be complicated by use of two-stage FB dryers which add ambient air streams at the discharge end of the dryer. There is a potential for circumventing concentration standards by diluting the exhaust gases discharged to the atmosphere with excess air, thus lowering the concentration of pollutants emitted but not the total mass emitted. For combustion operations, this problem can usually be overcome by correcting the concentration measured in the gas stream to a reference condition such as a specified oxygen or carbon dioxide percentage in the gas stream. However, in the AS industry the drying process frequently does not involve direct combustion. The drying air may be heated by an outside source; therefore, it is not always possible to "correct" the amount of exhaust air to account for dilution.

Because design dryer gas flow rates vary for process reasons, concentration standards applied to the ammonium sulfate industry would penalize those plant operators who chose to use a low air flow rate for the AS dryer. A decrease in the amount of dryer air decreases the volume of gases released but not necessarily the quantity of particulate matter emitted. As a result, the concentration of particulate matter in the exhaust gas stream would increase even though the total mass emitted might remain nearly the same.

Because mass standards directly limit the amount of particulate matter emitted to the atmosphere per megagram of AS production, a single mass standard can be applied to all dryer types and sizes, production rates, and air flow rates. The flexibility of mass standards to accommodate process variations, such as the wide range of gas-to-product ratios found in the industry, allows all segments of the AS industry to be regulated with a single mass emission limit. These advantages outweigh the drawbacks associated with the determination of process weight. Consequently, mass standards were judged more suitable for regulation of particulate emissions from AS dryers and were selected as the format for expressing the standard of performance for ammonium sulfate manufacturing plants.

The use of mass units results from discussion with control officials, representatives of affected industries, and others knowledgeable in the field. The purpose of using mass units is to facilitate enforcement of the new source performance standards as well as to allow plant operators to vary air flow according to the needs of the individual process involved.

In proposing mass limits, it is implicit that compliance be achieved through the application of remedial equipment that will limit the discharge of pollutants to the atmosphere. The mass limit recommended will apply to the exhaust gas streams as they discharge from control equipment. The proposed standard expresses allowable particulate emissions in kilograms of particulate per megagram of AS production.

9.5 SELECTION OF THE BEST SYSTEM OF EMISSION REDUCTION AND THE NUMERICAL EMISSION LIMITS

Best systems of emission reduction and emission limits were selected based on emission data and background information obtained through the following procedure. First, the known available source test emission data were obtained. These were supplemented with AS production information from industry publications and literature related to air pollution control and process equipment. Secondly, verbal and written communications were made with several representatives from manufacturing companies, trade associations, and air pollution control agencies. Finally, nine of the plants were visited to obtain process and emission control information. Relative control efficiencies of different types of control devices were evaluated on the basis of conversations with plant operators, test data (where available), and visual observations of opacity from control devices. Judgment regarding the feasibility of stack testing was made for each plant. Of the nine plants visited, five locations were unsatisfactory because the control equipment was judged to be less than optimum or the physical layout of the equipment made testing infeasible. One unit could not be tested because it was undergoing an equipment modification. Facilities at four plants were selected for stack testing using EPA Reference Method 5 to evaluate control techniques currently used for controlling particulate emissions from AS dryers. A description of the facilities and detailed results of the EPA emissions tests are presented in Chapter 4, Section 4.5 and in Appendix C.

9.5.1 Control Technology

Both venturi scrubbing and fabric filtration represent the most efficient add-on control techniques available to abate particulate emissions. In application to particulate collection from AS dryers, both have the potential to reduce AS emissions by over 99.9 percent and both can potentially reduce the AS emissions from process dryers to less than 0.15 kilogram per megagram of AS production, although energy requirements and costs may differ.

At present, a variety of wet-scrubbing systems are employed to control AS particulate emissions. The majority of these are low-energy wet-scrubbers; the only high-efficiency wet collectors that are being used with ammonium sulfate dryers are medium energy venturi scrubbers in use at two plants. EPA tests on medium energy venturi scrubbers controlling AS emissions show that greater than 99.9 percent particulate removal efficiency can be attained.

Several parameters affect the performance of wet-scrubbing systems; other parameters being equal, however, collection efficiency tends to increase with the increased energy input. Increases in the pressure drop and the liquid-to-gas ratio are directly related to increase in efficiency: the higher the pressure drop, the higher the removal efficiency of particulates. Pressure drop can be increased (and hence efficiency can be increased) simply by increasing the gas velocity and/or the water injection rate within the design limits of the control equipment. When gas cleaning requirements change, the only adjustment necessary to the venturi scrubber, in most cases, is in the flow of scrubbing liquid to increase the pressure drop. Thus, higher cleaning efficiency is accomplished without modification or addition.

Venturi scrubbers are most suitable for application to AS dryers. In caprolactam by-product AS plants, AS feed streams are used as a scrubbing liquor and in synthetic AS plants the condensate from the reactor/crystallizer is used as the scrubbing liquor. This allows the collected particulate to be easily recycled to the system without addition of excess water.

Because medium-energy (25 to 33 centimeters W.G. pressure drop) venturi scrubbing with high liquid-to-gas ratios achieves a high collection efficiency and because venturi scrubbing is compatible with and complimentary to the processes involved, it is considered the most attractive add-on control system.

The fabric filter baghouse should also be able to achieve the level of control required by the standard based on similar applications in other industries. Normal operation of a baghouse for AS particulate collection, i.e., at temperatures above the dewpoint of the exhaust gas, should be feasible. However, in assessing fabric filters as an emission control option, the following factors must be considered. For high gas flow rates, capital and operating costs as well as energy requirements are higher for fabric filters than for medium energy scrubbers of the same construction material (see Table 8-38). For caprolactam by-product plants using steam-heated fluidized bed dryers, the ratio of gas flow to product rate is at least an order of magnitude higher than that of the direct-fired rotary drum dryer operating with fabric filters. As the size of a baghouse becomes larger, capital and annual operating costs increase. For example, maintaining the temperature of the exhaust gas and baghouse surfaces above the dewpoint may require more energy than would ordinarily be required to operate the dryer.

With caprolactam by-product AS plants apparently providing the bulk of the anticipated growth in the AS industry, consideration should also be given to caprolactam hydrocarbon emissions from AS dryers. Available test data indicate that most of the caprolactam emissions associated with the AS dryer are in the vapor state. This suggests that caprolactam emissions would pass through a fabric filter collection system. On the other hand, a venturi scrubber has demonstrated removal efficiency of 88 percent of the caprolactam from AS dryers. Thus, use of venturi scrubbers would, at a minimum, maintain existing HC control levels now achieved by in-use wet collection systems.

9.5.2 Emission Tests

Of the four tests by EPA, one was conducted to determine the control level achievable by a low energy wet scrubber of the centrifugal type operating at a low pressure drop of 15 centimeters (6 inches W.G.) and low liquid-to-gas ratio of 267 liters/1000 m^3 (2 gallons per 1000 acf). Analysis of EPA test results at Plant C, a synthetic AS plant with a rotary drum dryer, indicates that this emission control equipment is not representative of the best available control technology. Observed opacities at Plant C range between 10 and 15 percent. Average controlled grain loading was 200 milligrams per dry standard cubic meter. The particulate collection efficiency at this facility was 97 percent. An inadequate control equipment performance might be expected from consideration of the pressure drop and L/G ratio together with the particle size distribution. Facility C had a size distribution of 5.9 percent of particles in the 0 to 1.11 micron range.

The facility did however achieve a low mass emission limit (0.08 kg/Mg of product). This was in large part a consequence of the low uncontrolled inlet emission rate brought about by a low gas-to-product ratio at this facility.

The one dry AS particulate control system in use (the fabric filter unit at Plant A) was tested because it represents a unique application of this control method in the AS manufacturing industry. Facility A, a synthetic AS plant with a rotary drum dryer, showed average particulate emissions of 0.007 kilograms per megagram of AS production and a collection efficiency of 98.7 percent.

Of the factors influencing emission rates at Plant A, one is most significant. The baghouse in use was originally designed for another application; the gas flow rate to this unit is appreciably lower than normal direct-fired gas flow. This constraint on gas flow rate, by restricting the ratio of dryer exhaust gas-to-product rate, results in a significantly lower uncontrolled inlet emission rate than most other dryers used in the industry. The fabric filter inlet uncontrolled emission rate was 0.41 kg/Mg of production. Those of facilities controlled by venturi scrubbers were 110 kg/Mg and 77 kg/Mg. This represents an uncontrolled mass emission difference in the range of two orders of magnitude. Comparison of the outlet mass emissions for this facility with those of the other facilities tested is, in this situation, somewhat misleading.

Facility D, a synthetic AS plant with a rotary drum dryer, is controlled by a venturi scrubber operating at a pressure drop of 33 centimeters (13 inches W.G.) and a L/G ratio of 3,600 liters/1000 m^3 (27 gallons per 1000 acf). Analysis of EPA test results at Plant D show a high uncontrolled emission rate entering the control device; the control system did however demonstrate the typically high control efficiency (99.8) percent) achievable with a venturi scrubber. The outlet emission rate, 192 milligrams per dry standard cubic meter and 0.158 kg/Mg of product, was affected by the high inlet emission load caused by a process variation at Plant D. It was indicated that the crystallizer at Plant D periodically goes into a fines cycle, lasting anywhere from 10 to 15 hours, during which time a much heavier proportion of AS fines is produced in the dryer product than is normal.

Facility B, a caprolactam by-product AS plant with a fluidized bed dryer, is also controlled by a venturi scrubber; in this case the unit operates at 25.9 centimeters (10 inches W.G.) pressure drop and a L/G ratio of 3,075 liters/1000 m^3 (24 gallons per 1000 acf). EPA test results show an average controlled outlet emission rate of 0.156 kg/Mg of AS production and 43 milligrams per dry standard cubic meter. The overall particle collection efficiency was 99.9 percent by weight, a control efficiency regarded as typical of venturi scrubbers. The mass emission level achieved at Plant B and the particular control equipment used are considered representative of best demonstrated control technology.

Additional emission test data have been provided by the AS plant operators. One facility's test results (using EPA Method 5) show an average emission rate of 0.135 kg/Mg of AS production. Facility E, a caprolactam AS plant with FB dryer, is controlled by a centrifugal scrubber preceded by a system of cyclones. The scrubber operated at

34 centimeters (13.4 inches) W.G. pressure drop and L/G ratio of 267 liters/1000 m^3 (2.0 gallons per 1000 acf). Although the L/G ratio is somewhat low, collection efficiency was enhanced by the cyclones which precede the scrubber; thus, a low outlet emission concentration was achieved.

Figure 1 presents the results of the four EPA emission tests and the one plant operator test in the format selected for the new source standard.

9.5.3 Regulatory Options

Review of the performance of the emission control techniques led to the identification of two regulatory options. The two options are based on emission control techniques representative of two distinct levels of control. Each option specifies numerical emission limits for AS dryers appliable to the three major sectors of the AS industry. Option I is equivalent to no additional regulatory action. Emission levels would be set by existing SIP regulations, typically in the range of 0.71 kg/Mg to 1.3 kg/Mg of AS production. This option is characterized by the use of a low energy wet scrubber to meet the required emission limit, a reduction of 97 to 98 percent. Option II, based on the use of a venturi scrubber or fabric filter, would set an emission limit of 0.15 kilogram per megagram of AS production, the level of emission control identified as achievable by EPA source tests. As applied to the AS industry, both the venturi scrubber and the fabric filter[3,4,5] control systems are capable of greater than 99.9 percent control efficiency; thus Option II represents the most stringent control level that can be met by all segments of the AS industry.

The environmental impacts, energy impacts, and economic impacts of each regulatory option were analyzed and compared using model plants for the new, modified, and reconstructed AS facilities. However, each AS manufacturing sector is unique from a technical standpoint. Dryer types and sizes, gas-to-product flow rates, and uncontrolled particulate emission rates vary from one sector to another and often within each

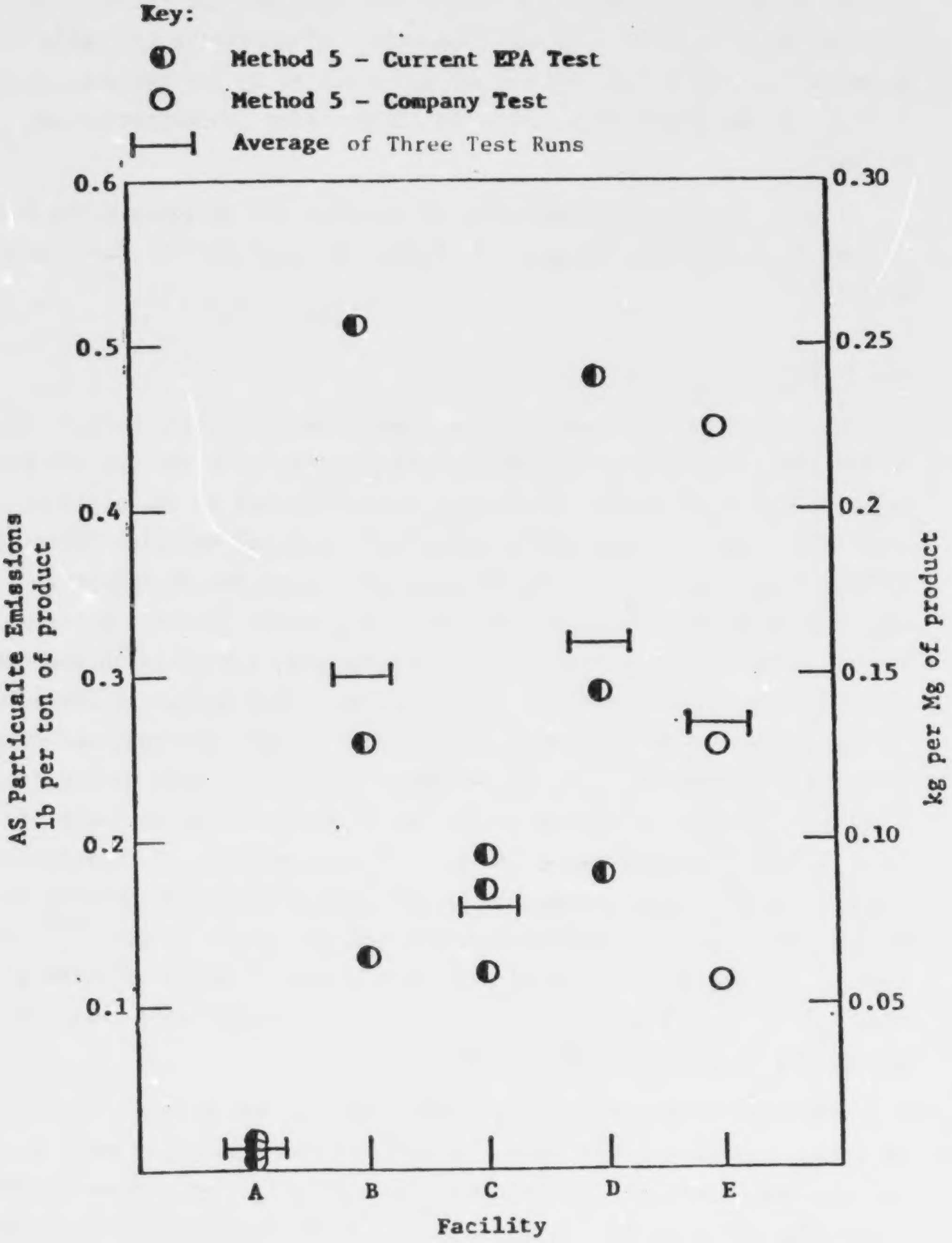

FIGURE 1
CONTROLLED AS PARTICULATE EMISSIONS FROM EPA EMISSION TESTS—CALCULATED MASS EMISSION RATES

sector. For these reasons it was apparent that no single model plant could adequately characterize the AS industry. Accordingly, several model dryers were specified in terms of the following parameters: production rate, dryer types, exhaust gas flow rates, emission rates, stack height, stack diameter, and exit gas temperatures. The description of the model plant parameters and the evaluation of the regulatory options as applied to the model plants are found in Chapters 6, 7, and 8.

Under Option I, new manufacturing plants' annual nationwide particulate emissions would increase by about 670 Mg/year (737 tons/year) between 1980 and 1985. Under Option II, nationwide emissions would increase by 131 Mg/year (144 tons/year). This represents a reduction of about 538 Mg/year or 80 percent in the emissions that would be emitted under a typical SIP regulation.

The results of the dispersion analysis under "worst case"* meteorological conditions show the maximum 24-hour concentration of particulates in the vacinity of a new AS plant would be reduced by a factor of 80 percent (from 224 to 47.4 micrograms per cubic meter) by controlling to Option II rather than the SIP emission limit. The maximum annual average is reduced from 29.1 to 6.15 micrograms per cubic meter under Option II. Thus, the implementation of Option II would result in reduction of ambient air concentration of particulate matter in the vicinity of new, modified, or reconstructed AS plants.

Effluent guidelines set forth in 40 CFR 418.60 limit water pollution from synthetic and coke oven AS plants. The caprolactam by-product AS plant has a comparatively large throughput of water. This water is removed in the crystallizer, condensed and recycled to the principal plant for plant use. The addition of a wet scrubber for emission control would not create a water pollution problem since all scrubbing liquor would be recycled to the process. The same would be true with a baghouse since it is a dry collection system. Consequently, the water pollution impact of Option II is zero.

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*Worst case conditions refer to the atmospheric and meteorological conditions that result in the highest pollutant concentrations.

The AS plants generate no solid waste as part of the process since all collected AS is recycled to the process. Furthermore, no significant increase in noise level is anticipated under Option II.

For typical plants in the AS manufacturing industry, an increase in energy consumption would result from compliance with Option II. The energy required, in excess of that required by a typical SIP regulation, to control new caprolactam by-product AS plant to the level of Option II would be 8.8 gigawatt-hours of electricity per year in 1985 using venturi scrubbers. The overall energy increase would amount to less than 0.65 percent of the total energy required to run the plant. For synthetic and coke-oven AS plants, the 1985 incremental energy increase would be 0.61 and 0.14 gigawatt hours per year, respectively, or less than a 0.1 percent increase. The total energy increment would be 9.5 gigawatt hours per year in 1985. These figures indicate that Option II would not significantly increase energy consumption at AS plants and that Option II would have a minimal impact on national energy consumption.

Economic analysis also indicates that the impact of Option II is minimal. The capital cost of the installed emission control equipment necessary to meet Option II, on all new and reconstructed AS facilities coming on-line nationwide during the period 1980 to 1985, would be about $958,000. The total annualized cost of operating this equipment during the same period would be about $480,200. These costs are considered reasonable, and are not expected to prevent or hinder expansion or continued production in the AS manufacturing industry. The incremental cost necessary to offset the cost of meeting Option II would be about 0.01 percent of the wholesale price of AS.

Consideration of the beneficial impact on national particulate emissions; the lack of water pollution impact or solid waste impact;

and the minimal energy impact; the reasonable cost impact; and the general availability of demonstrated emission control technology leads to the selection of Option II as the basis for standards of performance for new AS dryers.

9.6 SELECTION OF OPACITY LIMITS

The best indirect method of ensuring proper operation and maintenance of emission control equipment is the specification of exhaust gas opacity limits. Determining an acceptable exhaust gas opacity limit is possible because opacity levels were evaluated for AS dryers during EPA tests; therefore, the data base for the particulate standards includes information on opacity. A standard of 15 percent opacity is proposed for all affected facilities to ensure proper operation and maintenance of control systems on a day-to-day basis. Ammonium sulfate dryers were observed to have no opacity readings greater than 15 percent opacity, and a total of 90 minutes of opacity of less than or equal to 15 percent but greater than 10 percent during observation periods of 180, 120, 438, and 408 minutes (1146 minutes total). The results of these observations are summarized in Table 9-2.

9.7 SELECTION OF PERFORMANCE TEST METHODS

The use of EPA Reference Method 5 — "Determination of Particulate Emissions from Stationary Sources" (40 CFR Part 60, Appendix A) would be required to determine compliance with the mass standards for particulate matter emissions. Results of performance tests using Method 5 conducted by EPA on existing ammonium sulfate dryers comprise a major portion of the data base used in the development of the proposed standard. EPA Reference Method 5 has been shown to provide a representative measurement of particulate matter emissions. Therefore, it is included for determining compliance with the proposed standards.

Method 5 calculations require input data obtained from three other EPA test methods conducted previous to the performance of Method 5. Method 1 — "Sample and Velocity Traverse for Stationary

Table 2. OPACITY OBSERVATIONS

Percent Opacity	Facility				Total Observation Time (Minutes)
	A	B	C	D	
>10 and ≤15	0	36	54	0	90
>5 and ≤10	0	186	66	0	252
>0 and ≤ 5	0	198	0	318	516
0 Percent	180	18	0	90	288
Total Observation Time (Minutes)	180	438	120	408	1,146

Sources" must be used to obtain representative measurements of pollutant emissions. The average gas velocity in the exhaust stack is measured by conducting Method 2, "Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S Pitot Tube)." The analysis of gas composition is measured by conducting Method 3, "Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight." These three tests provide data necessary in Method 5 for determining concentration of particulate matter in the dryer exhaust. All opacity observations would be made in accordance with the procedures established in EPA Method 9 for stack emissions.

Since the proposed standards are expressed as mass of emissions per unit mass of ammonium sulfate production, it will be necessary to quantify production rate in addition to measuring particulate emissions. Ammonium sulfate production in megagrams shall be determined by direct measurement using product weigh scales or computed from a material balance. A material balance computation based on the chemical reactions used in the formation of ammonium sulfate is an acceptable method of determining production rate since the formation reactions used in all industrial sectors are quantitative and irreversible.

If a material balance is used, the ammonium sulfate production rate for synthetic and coke oven by-product ammonium sulfate plants shall be calculated from the metered sulfuric acid feed rate to the reactor/crystallizer. For caprolactam by-product ammonium sulfate plants, production rate shall be determined from the oximation ammonium sulfate solution flow rate and the oleum flow to the caprolactam rearrangement reaction.

9.8 SELECTION OF MONITORING REQUIREMENTS

To further ensure that installed emission control systems continuously comply with standards of performance through proper operation and maintenance, monitoring requirements are generally included in standards of performance. In the case of ammonium sulfate dryers, the most straightforward means of ensuring proper operation and maintenance is to require monitoring of actual particulate emissions released to the atmosphere. Currently, however, there are no continuous particulate monitors in operation for AS dryers; and resolution of the sampling problems and development of performance specifications for continuous particulate monitors would entail a major development program. For these reasons, continuous monitoring of particulate emissions from AS dryers is not required by the proposed standards.

The best indirect method of monitoring proper operation and maintenance of emission control equipment is to continuously monitor the opacity of the exhaust gas. The proposed opacity limit for AS dryers is 15 percent. However, in the case of AS dryers, the character of the exhaust gas when wet scrubbers are used for emission reduction precludes the use of continuous in-stack opacity monitors. Where condensed moisture is present in the exhaust gas stream, in-stack continuous monitoring of opacity is not feasible; water droplets and steam can interfere with operation of the monitoring instrument. Since most new facilities are likely to use wet scrubbers, continuous monitoring of opacity is not required by the proposed standards.

An alternative to particulate or opacity monitors is the use of pressure drop monitor as a means of ensuring proper operation and maintenance of emission control equipment. For venturi scrubbers, particulate removal efficiency is related directly to pressure drop across the venturi; the higher the pressure drop, the higher the removal efficiency. For fabric filters, pressure drop is used as an indicator of excessive filter resistance or damaged filter media. Therefore, in order to provide a continuous indicator of emission control equipment operation and maintenance, the proposed standards require that the owner or operator of any ammonium sulfate manufacturing plant subject to the standards install, calibrate, maintain, and operate a monitoring device which continuously measures and permanently records the total pressure drop across the process emission control system. The monitoring device shall have an accuracy of ±5 percent over its operating range.

The proposed standards would also require the owner or operator of any ammonium sulfate manufacturing plant subject to the standards to install, calibrate, maintain, and operate flow monitoring devices necessary to determine the mass flow of ammonium sulfate feed material to the process. The flow monitoring device shall have an accuracy of ±5 percent over its operating range. The AS feed streams are: for synthetic and coke oven by-product AS plants, the sulfuric acid feed stream to the reactor/crystallizer; for caprolactam by-product AS plants, the oximation AS stream to the AS plant and the oleum stream to the caprolactam rearrangement reaction.

Records of pressure drop and calibration measurements would have to be retained for at least 2 years following the date of the measurements by owners and operators subject to this subpart. This requirement is included under 60.7(d) of the general provisions of 40 CFR Part 60.

9.9 References

1. Bell, K.A., W.S. Linn, and J.D. Hackney, Effects of Sulphate Aerosals Upon Human Cardiopulmonary Function, CRC-APRAC-CAPM-27-75, May 1977.

2. Gooleski and Leighton, Studies on the Effect of AS on Carcinogenesis. EPA 600/1-78-020, March 1978.

3. Air Pollution Engineering Manual, 2nd Edition, EPA, AP-40, p. 111-132. May 1973.

4. Information provided by McIlwaine Company in a telephone conversation between M. McIlwaine and R. Zerbonia, PES, May 2, 1979.

5. Control Techniques for Particulate Air Pollutants, U.S. Environmental Protection Agency, AP-51, p. 118.

APPENDIX A

EVOLUTION OF THE PROPOSED STANDARDS

APPENDIX A. EVOLUTION OF THE PROPOSED STANDARDS

In early 1978, the Argonne National Laboratory prepared a list of 156 major source categories and ranked them in order of priority for NSPS development. The method used to rank the source categories was based on emissions, public health/welfare, and source mobility which were criteria set forth by the Congress in the 1977 Clean Air Act Amendments. Ammonium sulfate was ranked 44th in priority on a list of 72 source categories selected by EPA.

Based upon the results of a screening study conducted in March 1978, standards development was initiated for the AS category.

In May 1978, a literature survey was begun and the industry was canvassed by phone to obtain information on plant operations and to determine which plants, if any, appear to be well controlled. Plant visits were then scheduled to obtain information on process details, quantities of emissions, and emission control equipment. The feasibility of emission testing was also determined during the plant visits. The significant events relating to this effort are discussed in the chronology below.

A.1 CHRONOLOGY

The chronology to follow lists the important events which have occurred in the development of background information for a New Source Performance Standard for Ammonium Sulfate Manufacturing.

Date	Activity
October 14, 1977	Literature survey initiated for screening study. Telephone survey of AS plants initiated.
March 21, 1978	Screening study completed. A decision was made to initiate standards development.
January 3, 1978 - April 20, 1978	Section 114 letters sent.
April 13, 1978	Project starting date. Contract awarded to MITRE
June 6, 1978	Plant visit to the Allied Chemical Corp., caprolactam plant in Hopewell, Virginia.
June 7, 1978	First contact with the Industrial Gas Cleaning Institute (IGCI) regarding control technology for AS dryer emissions.
June 12, 1978	Plant visit to the Rohm and Haas acrylate production facility in Pasadena, Texas.
July 31, 1978	Initial test request submitted to EMB.
August 31, 1978	Preliminary model plant data submitted to EMB
June 12, 1978	Plant visit to the Occidental Chemical Company in Houston, Texas.
June 13, 1978	Plant visit to the Dow-Badische Chemical Company caprolactum plant at Freeport, Texas.
June 20, 1978	Plant visit to the Bethlehem Steel Company coke oven by-product AS plant.
June 26, 1978	Plant visit to the Chevron Chemical Company synthetic AS production facility at Richmond, California.
June 27, 1978	Plant visit to the Valley Nitrogen Producers Company synthetic AS plant at Helm, California.

Date	Activity
June 28, 1978	Plant visit to the Occidental Chemical Company synthetic AS production facility at Lathrop, California.
July 25, 1978	Plant visit to the Nipro Chemical Company caprolactam production facility in Augusta, Georgia.
September 12, 1978	Emission testing at Plant A.
October 3, 4, 1978	Emission testing at Plant B.
October 6-12, 1978	Telephone survey of coke oven facilities.
October 26, 1978	Emissions testing at Plant A for additional information.
November 31, 1978	Final model plant parameters submitted to EMB.
December 5, 6, 1978	Emission testing at Plant C.
December 12, 13, 1978	Emission testing at Plant D.
January 31, 1979	Complete test results received from EMB.
February 28, 1979	Preliminary cost analysis available from EMB.
March, 1979	Completion of technical portion of BID, Chapters 3-7.
April, 1979	Industrial mailout of BID Chapters 3-7.
April, 1979	Completion of NSPS economic analysis, Chapter 8; Rationale, Chapter 9; and Preamble.
May, 1979	EPA Working Group mailout.
June, 1979	Revision of BID chapters, Regulation, and Preamble to account for Working Group and Industry comment.
June, 1979	EPA Steering Committee mailout.

Date	Activity
August 13, 1979	Mailout to Industry, Environmental Groups and other Government Agencies (BID, Regulation, and Preamble).
August 28, 1979	National Air Pollution Control Techniques Advisory Committee meeting for review of BID, Regulation, and Preamble).

APPENDIX B

INDEX TO ENVIRONMENTAL CONSIDERATIONS

APPENDIX B

INDEX TO ENVIRONMENTAL CONSIDERATIONS

This appendix consists of a reference system which is cross indexed with the October 21, 1974, Federal Register (39 FR 37419) containing EPA guidelines for the preparation of Environmental Impact Statements. This index can be used to identify sections of the document which contain data and information germane to any portion of the Federal Register guidelines.

APPENDIX B

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document (BID)
1. Background and Description of Proposed Action	
Summary of Proposed Standard	The standards are summarized in Chapter 1, Section 1.1.
Statutory Basis for the Standard	The statutory basis for the standard is given in Chapter 2.
Facility Affected	A description of the facility to be affected is given in Chapter 3, Section 3.1.
Process Affected	A description of the process to be affected is given in Chapter 3, Section 3.2.
Availability of Control Technology	Information on the availability of control technology is given in Chapter 4.
Existing Regulations at State or Local Level	A discussion of existing regulations or the industry to be affected by the standards is included in Chapter 3, Section 3.2.
2. Alternatives to the Proposed Action	
Option I	
Environmental Impacts	The environmental impacts associated with Option I emission control systems are considered in Chapter 7.
Costs	The cost impact of Option I emission control systems is considered in Chapter 8, Section 8.2.

(Continued)

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS (Concluded)

Agency Guidelines for Preparing Regulatory Action Environmental Impact Statements (39 FR 37419)	Location Within the Background Information Document (BID)
Health and Welfare Impact	The impact of Option I emission control systems on health and welfare is considered in Chapter 7.
3. Environmental Impact of Proposed Action	
Air Pollution	The air pollution impact of the proposed standards is considered in Chapter 7, Section 7.1.
Water Pollution	The impact of the proposed standards on water pollution is considered in Chapter 7, Section 7.1.
Solid Waste Disposal	The impact of the proposed standards on solid waste disposal is considered in Chapter 7, Section 7.3.
Energy	The impact of the proposed standards on energy use is considered in Chapter 7, Section 7.4.
Costs	The impact of the proposed standards on costs is considered in Chapter 8, Section 8.2

APPENDIX C

SUMMARY OF TEST DATA

APPENDIX C. SUMMARY OF TEST DATA

A test program was undertaken by EPA to evaluate the best demonstrated control technology available in the AS production industry, for controlling particulate emissions from the AS dryer. This appendix summarizes the results of the particulate emission tests and visible emission observations.

One baghouse and three wet scrubbers (two venturi and one centrifugal scrubber) were tested using EPA Reference Method 5. Results of the front-half catches (probe and filter) from the particulate emission measurements conducted are shown in Figures C-1 through C-4. The controlled particulate emission values are displayed in concentration and mass units in these figures. In addition, pertinent industry-supplied data are shown in Figures C-1 through C-4. Complete EPA emission test results are presented in Tables C-1 through C-21.

Visible emission observations were made at the exhaust of the above control devices in accordance with procedures recommended in EPA Reference Method 9 for visual determination of the opacity of emissions from stationary sources. Results of opacity determinations at the four facilities tested are summarized in Tables C-2, C-3, C-5, C-7 and C-9, respectively, and presented in detail in Tables C-17 through C-21.

C.1 DESCRIPTION OF FACILITIES

Plant A

Gas-fired rotary dryer rated at 16.3 Mg/hr (18 TPH). AS particulate emissions are collected by a reverse jet type baghouse. Two sets of baghouse outlet emission tests were conducted at Plant A using EPA Method 5. The first set of outlet tests (Table C-2) was rejected due to discovery of some punctured bags which resulted in an abnormally high grain loading result. The second set of baghouse outlet tests (Table C-3) was conducted during a period of normal operation. Uncontrolled AS emissions and particle size distribution data were determined at the baghouse inlet (Tables C-1 and C-13, respectively). Visible emission observations were made at the baghouse exhaust using EPA Method 9 (Table C-17).

Plant B

Fluidized-bed dryer rated at 26.5 Mg/hr (29.2 TPH). The AS bed in this unit is fluidized by two streams of air: steam-heated air for drying the moisture-laden AS, introduced at the front end of the dryer, and ambient air for cooling of the AS product introduced at the back end of the dryer. AS particulate emissions from the dryer are controlled by a venturi scrubber. Emission tests were conducted only during periods when the process was operating normally. Scrubber inlet and outlet AS particulate levels were measured using EPA Method 5 (Tables C-4 and C-5). Particle size distribution data were determined at the scrubber inlet (Table C-14). Visible emission observations were made of the stack gas leaving the scrubber using EPA Method 9 (Table C-18). Since Plant B is a caprolactam AS production facility, measurements were made of caprolactam emissions at both the scrubber inlet and outlet. Actual determinations of caprolactam concentrations were made using gas chromatograph methods and results are shown in Tables C-11 and C-12.

Plant C

Gas-fired rotary dryer rated at 15.2 Mg/hr (16.7 TPH). AS particulate emissions are collected by a wet scrubber of the centrifugal type. Emission tests were conducted during periods of normal operation. Scrubber inlet and outlet AS particulate levels were measured using EPA Method 5 (Tables C-6 and C-7). Particle-size distribution data were determined at the scrubber inlet (Table C-15). Visible emission observations were made of the stack gas leaving the scrubber using EPA Method 9 (Table C-19).

Observed opacities at Plant C range between 10 and 15 percent during the test. Controlled grain loading averaged 0.20 gr/dscm. The control equipment in this case is a centrifugal scrubber designed for a ΔP of approximately 6" W.G. and an L/G ratio of about 5.0 gal/1000 acfm. Actual values of these parameters could not be calculated from the available test data so it is not known whether one or both of these key scrubber factors were operating at design values.

Plant D

Gas-fired rotary dryer rated at 8.4 Mg/hr (9.2 TPH). AS particulate emissions are collected by a venturi scrubber. Scrubber inlet and outlet AS particulate levels were measured using EPA Method 5 (Tables C-8 and C-9). Particle-size distribution data were determined at the scrubber inlet (Table C-16). Visible emission observations were made of the stack gas leaving the scrubber using EPA Method 9 (Table C-20).

Observed opacities at Plant D were 0 percent during the test. Controlled grain loading averaged 0.192 grams/dscm. The control equipment in this case, a venturi scrubber, is designed for a ΔP of approximately 13 inches W.G. and a L/G ratio of about 27 gal/1000 acf. Actual values of these parameters could not be calculated from the available test data; so it is not known whether one or both of these key scrubber factors were operating at design values. The company, however, is not able to provide the original design data for this unit which was installed in 1965.[1] With respect to variations in process operation, it was indicated that the crystallizer at Plant D periodically goes into a fines cycle, lasting anywhere from 10 to 15 hours, during which time a much heavier proportion of AS fines is produced in the dryer product than is usual (approximately 4 to 5 times the normal amount).[2]

C.2 REFERENCES

1. Information provided by Plant D in a telephone conversation with Marvin Drabkin of The MITRE Corporation, Metrek Division, on March 28, 1979.

2. Information provided by Plant D in a letter to Marvin Drabkin of The MITRE Corporation, Metrek Division, dated March 16, 1979.

Table C-1. FACILITY A - FIRST SET OF TESTS SUMMARY OF RESULTS - BAGHOUSE INLET

Run Number	1	2	3	Average
Date	9/12/78	9/12/78	9/13/78	
Test Time-Minutes	120	120	120	120
AS Production Rate - Mg/hr	15.8	14.9	18.7	16.4
(TPH)	(17.4)	(16.4)	(20.6)	(18.1)
Dryer Vent Gas Data				
Flow rate - acm/min	36.7	37.2	37.2	37
(acfm)	(1300)	(1320)	(1320)	(1310)
Flow rate - dscm/min	27.1	26.8	26.8	26.8
(dscfm)	(960)	(950)	(950)	(950)
Temperature - °C	67	80	76	74
(°F)	(153)	(176)	(170)	(166)
Water vapor - Vol. %	12.9	12.4	13.0	12.8
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	2.29	2.17	8.69	4.38
(gr/dscf)	(1.01)	(0.96)	(3.83)	(1.93)
gm/acm	1.70	1.56	6.26	3.17
(gr/acf)	(0.75)	(0.69)	(2.76)	(1.40)
kg/hr	3.8	3.56	14.1	7.1
(lb/hr)	(8.36)	(7.84)	(31.2)	(15.8)
kg/Mg	0.24	0.24	0.75	0.41
(lb/ton)	(0.48)	(0.48)	(1.51)	(0.82)
Total Catch				
gm/dscm				
(gr/dscf)				
gm/acm		(Data not determined)		
(gr/acf)				
kg/hr				
(lb/hr)				
kg/Mg				
(lb/ton)				

Table C-2. FACILITY A - FIRST SET OF TESTS
SUMMARY OF RESULTS - BAGHOUSE OUTLET

Run Number	1	2	3	Average
Date	9/12/78	9/12/78	9/13/78	
Test Time-Minutes	120	120	120	120
AS Production Rate - Mg/hr	15.8	14.9	18.7	16.4
(TPH)	(17.4)	(16.4)	(20.6)	(18.1)
Stack Gas Data				
Flow rate - acm/min	35.5	34.4	33.6	34.5
(acfm)	(1260)	(1220)	(1190)	(1223)
Flow rate - dscm/min	27.6	26.8	26.2	26.9
(dscfm)	(980)	(950)	(930)	(955)
Temperature - °C	55	59	58	57
(°F)	(131)	(139)	(138)	(136)
Water vapor - Vol. %	13.7	11.8	12.3	12.6
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	0.063	0.192	0.211	0.155
(gr/dscf)	(0.028)	(0.085)	(0.093)	(0.069)
gm/acm	0.049	0.149	0.165	0.122
(gr/acf)	(0.022)	(0.066)	(0.073)	(0.054)
kg/hr	0.109	0.318	0.336	0.254
(lb/hr)	(0.24)	(0.70)	(0.74)	(0.56)
kg/Mg	0.007	0.021	0.018	0.015
(lb/ton)	(0.014)	(0.043)	(0.036)	(0.031)
Total Catch				
gm/dscm				
(gr/dscf)				
gm/acm				
(gr/acf)		(Data not determined)		
kg/hr				
(lb/hr)				
kg/Mg				
(lb/ton)				

Table C-2 (continued). FACILITY A - FIRST SET OF TESTS
SUMMARY OF RESULTS - BAGHOUSE OUTLET

Baghouse Particulate				
Removal Efficiency	97.2	91.1	97.6	95.3
Visible Emissions				
≤ 5 percent opacity, minutes observed	0	0	0	
0 percent opacity, minutes observed	0	0	0	
No visible emissions, minutes observed	120	120	120	

Table C-3. FACILITY A - SECOND SET OF TESTS SUMMARY OF RESULTS - BAGHOUSE OUTLET

Run Number	1	2	3	Average
Date	10/26/78	10/26/78	10/26/78	
Test Time-Minutes	60	60	60	60
AS Production Rate - Mg/hr (TPH)	13.6 (15.0)	13.6 (15.0)	14.18 (15.6)	13.9 (15.4)
Stack Gas Data				
Flow rate - acm/min (acfm)	39.2 (1390)	38.9 (1380)	38.7 (1370)	38.9 (1380)
Flow rate - dscm/min (dscfm)	33.8 (1200)	31.9 (1130)	32.2 (1140)	32.6 (1157)
Temperature - °C (°F)	45 (114)	45 (114)	49 (121)	46 (116)
Water vapor - Vol. %	7.3	11.6	9.6	9.5
Particulate Emissions				
Probe and Filter Catch				
gm/dscm (gr/dscf)	0.036 (0.016)	0.052 (0.023)	0.059 (0.026)	0.049 (0.022)
gm/acm (gr/acf)	0.031 (0.014)	0.043 (0.019)	0.049 (0.022)	0.040 (0.018)
kg/hr (lb/hr)	0.07 (0.16)	0.10 (0.23)	0.11 (0.25)	0.09 (0.21)
kg/Mg (lb/ton)	0.005 (0.011)	0.007 (0.015)	0.009 (0.016)	0.009 (0.014)
Total Catch				
gm/dscm (gr/dscf)				
gm/acm (gr/acf)		(Data not determined)		
kg/hr (lb/hr)				
kg/Mg (lb/ton)				

Table C-3 (continued). FACILITY A - SECOND SET OF TESTS SUMMARY OF RESULTS - BAGHOUSE OUTLET

Baghouse Particulate				
Removal Efficiency	--	--	--	98.7[a]
Visible Emissions				
≤5 percent opacity, minutes observed	0	0	0	
0 percent opacity, minutes observed	0	0	0	
No visible emissions, minutes observed	60	60	60	

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[a] Based on average inlet pounds per hour measured in the earlier tests (Table C-1) and the average outlet pounds per hour derived from this set of tests.

Table C-4. FACILITY B
SUMMARY OF RESULTS - SCRUBBER INLET

Run Number	1	2	3	Average
Date	10/3/78	10/4/78	10/4/78	
Test Time-Minutes	120	120	120	120
AS Capacity* - Mg/hr	26.5	26.5	26.5	26.5
(TPH)	(29.2)	(29.2)	(29.2)	(29.2)
Dryer Vent Gas Data				
Flow rate - acm/min	1500	1491	1494	1494
(acfm)	(53,100)	(52,800)	(52,900)	(52,900)
Flow rate - dscm/min	1214	1194	1192	1200
(dscfm)	(43,000)	(42,300)	(42,200)	(42,500)
Temperature - °C	83	86	86	85
(°F)	(182)	(188)	(188)	(185)
Water vapor - Vol. %	3.5	3.7	4.0	3.7
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	39.7	37.4	40.1	39.0
(gr/dscf)	(17.5)	(16.5)	(17.7)	(17.2)
gm/acm				
(gr/acf)				
kg/hr	2927	2713	2913	2850
(lb/hr)	(6,440)	(5,970)	(6,410)	(6,270)
kg/Mg	110.5	102	114.5	110.5
(lb/ton)	(221)	(204)	(229)	(221)

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*Plant B was operating close to capacity at the time of testing. Actual production rate is held company-confidential.

Table C-4 (continued). FACILITY B
SUMMARY OF RESULTS - SCRUBBER INLET

Total Catch				
gm/dscm (gr/dscf)	39.7 (17.5)	37.4 (16.5)	40.1 (17.7)	39.0 (17.2)
gm/acm (gr/acf)				
kg/hr (lb/hr)	2927 (6,440)	2713 (5,970)	2913 (6,410)	2850 (6,270)
kg/Mg (lb/ton)	110.5 (221)	102 (204)	114.5 (229)	110.5 (221)

Table C-5. FACILITY B
SUMMARY OF RESULTS - SCRUBBER OUTLET

Run Number	1	2	3	Average
Date	10/3/78	10/4/78	10/4/78	
Test Time-Minutes	120	120	120	120
AS Capacity* - Mg/hr	26.5	26.5	26.5	26.5
(TPH)	(29.2)	(29.2)	(29.2)	(29.2)
Stack Gas Data				
Flow rate - acm/min	1646	1629	1644	1641
(acfm)	(58,300)	(57,700)	(58,200)	(58,100)
Flow rate - dscm/min	1443	1418	1440	1435
(dscfm)	(51,100)	(50,200)	(51,000)	(50,800)
Temperature - °C	40	43	40	41
(°F)	(105)	(110)	(104)	(106)
Water vapor - Vol. %	6.1	6.1	6.4	6.2
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	0.038	0.018	0.072	0.043
(gr/dscf)	(0.017)	(0.008)	(0.032)	(0.019)
gm/acm	0.034	0.015	0.063	0.038
(gr/acf)	(0.015)	(0.007)	(0.028)	(0.017)
kg/hr	3.40	1.62	6.45	3.83
(lb/hr)	(7.50)	(3.58)	(14.2)	(8.43)
kg/Mg	0.13	0.06	0.24	0.14
(lb/ton)	(0.26)	(0.12)	(0.49)	(0.29)
Total Catch				
gm/dscm	0.408	0.022	0.081	0.047
(gr/dscf)	(0.018)	(0.010)	(0.036)	(0.021)
gm/acm				
(gr/acf)				
kg/hr	3.61	1.87	7.13	4.20
(lb/hr)	(7.96)	(4.13)	(15.7)	(9.26)
kg/Mg	0.13	0.07	0.27	0.156
(lb/ton)	(0.27)	(0.14)	(0.54)	(0.32)

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*Plant B was operating close to capacity at the time of testing. Actual production rate is held company-confidential.

Table C-5 (continued). FACILITY B
SUMMARY OF RESULTS -
SCRUBBER OUTLET

Scrubber Particulate Removal Efficiency	99.9	99.9	99.8	99.9
Visible Emissions				
≤ 15 percent opacity, minutes observed	27			
≤ 10 percent opacity, minutes observed	93		38	
≤ 5 percent opacity, minutes observed		30	82	
0 percent opacity, minutes observed		90		

Table C-6. FACILITY C
SUMMARY OF RESULTS - SCRUBBER INLET

Run Number	1	2	3*	Average
Date				
Test Time-Minutes	1000	30		65
AS Production Rate - Mg/hr (TPH)	6.09 (16.7)	6.09 (16.7)		6.09 (16.7)
Dryer Vent Gas Data				
Flow rate - acm/min (acfm)	131.4 (4654)	131.8 (4666)	- -	131.5 (4660)
Flow rate - dscm/min (dscfm)	99.9 (3537)	92.9 (3290)	- -	96.4 (3414)
Temperature - °C (°F)	84 (184)	82 (181)	- -	83 (183)
Water vapor - Vol. %	7.2	14.2	-	10.7
Particulate Emissions				
Probe and Filter Catch				
gm/dscm (gr/dscf)	11.39 (5.02)	6.35 (2.80)	- -	8.87 (3.91)
gm/acm (gm/acm)	8.64 (3.81)	4.47 (1.97)	- -	6.56 (2.89)
kg/hr (lb/hr)	69.1 (152.2)	3.58 (7.89)	- -	52.5 (115.6)
kg/Mg (lb/ton)	4.55 (9.11)	2.56 (4.72)	- -	3.46 (6.92)
Total Catch				
gm/dscm (gr/dscf)				
gm/acm (gr/acf)		(Data not determined)		
kg/hr (lb/hr)				
kg/Mg (lb/ton)				

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*Results of this run not included due to non-isokinetic sampling

Table C-7. FACILITY C
SUMMARY OF RESULTS -
SCRUBBER OUTLET

Run Number	1	2	3	Average
Date	12/6/78	12/6/78	12/6/78	
Test Time-Minutes	60	60	60	60
AS Production Rate - Mg/hr	15.1	15.1	15.1	15.1
(TPH)	(16.7)	(16.7)	(16.7)	(16.7)
Stack Gas Data				
Flow rate - acm/min	121	120	119	120
(acfm)	(4313)	(4255)	(4245)	(4271)
Flow rate - dscm/min	97	93	100	96
(dscfm)	(3436)	(3304)	(3542)	(3427)
Temperature - °C	60	60	57	59
(°F)	(140)	(140)	(136)	(139)
Water vapor - Vol. %	9.6	11.9	6.2	9.2
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	0.155	0.256	0.208	0.206
(gr/dscf)	(0.0686)	(0.1132)	(0.0918)	(0.091)
gm/acm	0.124	0.199	0.173	0.165
(gr/acf)	(0.0547)	(0.0879)	(0.0766)	(0.073)
kg/hr	0.90	1.45	1.27	1.22
(lb/hr)	(2.0)	(3.2)	(2.8)	(2.7)
kg/Mg	0.06	0.095	0.085	0.08
(lb/ton)	(0.12)	(0.19)	(0.17)	(0.16)
Total Catch				
gm/dscm				
(gr/dscf)				
gm/acm		(Data not determined)		
(gr/acf)				
kg/hr				
(lb/hr)				
kg/Mg				
(lb/ton)				

Table C-7 (continued). FACILITY C SUMMARY OF RESULTS - SCRUBBER OUTLET

Scrubber Particulate Removal Efficiency	98.7	95.9	-*	97.3
Visible Emissions				
10-15 percent opacity, minutes observed	--	60	--**	
≤10 percent opacity, minutes observed	60			

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*Run No. 3 did not produce usable inlet data

**No opacity data obtained due to darkness

Table C-8. FACILITY D
SUMMARY OF RESULTS - SCRUBBER INLET

Run Number	1*	2	3**	4	Average
Date	12/12/78	12/12/78	12/13/78	12/13/78	
Test Time-Minutes	--	110	--	50	80
AS Production Rate - Mg/hr	--	8.4	8.4	8.4	8.4
(TPH)	--	(9.3)	(9.3)	(9.3)	(9.3)
Dryer Vent Gas Data					
Flow rate - acm/min	--	131	--	143	137
(acfm)	--	(4652)	--	(5092)	(4872)
Flow rate - dscm/min	--	102	--	113	107
(dscfm)	--	(3612)	--	(3994)	(3803)
Temperature - °C	--	81	--	82	82
(°F)	--	(178)	--	(181)	(180)
Water vapor - Vol. %	--	7.4	--	6.1	6.8
Particulate Emissions					
Probe and Filter Catch					
gm/dscm	--	103.23	--	95.45	98.29
(gr/dscf)	--	(45.48)	--	(42.05)	(43.3)
gm/acm	--	80.15	--	74.93	77.63
(gr/acf)	--	(35.31)	--	(33.01)	(34.2)
kg/hr	--	640	--	654	647
(lb/hr)	--	(1408)	--	(1439)	(1424)
kg/Mg	--	75.5	--	77.5	76.5
(lb/ton)	--	(151)	--	(155)	(153)
Total Catch					
gm/dscm					
(gr/dscf)					
gm/acm		(Data not determined)			
(gr/acf)					
kg/hr					
(lb/hr)					
kg/Mg					
(lb/ton)					

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*Run No. 1 aborted due to test difficulties
**Run No. 3 data found to be invalid due to leak in sampling equipment

Table C-9. FACILITY D
SUMMARY OF RESULTS - SCRUBBER OUTLET

Run Number	1	2	3	Average
Date	12/12/78	12/12/78	12/13/78	
Test Time-Minutes	120	120	120	120
AS Production Rate - Mg/hr	8.45	8.45	8.45	8.45
(TPH)	(9.3)	(9.3)	(9.3)	(9.3)
Stack Gas Data				
Flow rate - acm/min	131	124	139	131
(acfm)	(4663)	(4399)	(4929)	(4664)
Flow rate - dscm/min	113	108	120	114
(dscm)	(4027)	(3830)	(4256)	(4038)
Temperature - °C	45	43	45	45
(°F)	(114)	(111)	(114)	(113)
Water vapor - Vol. %	7.4	7.1	7.1	7.4
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	0.179	0.118	0.254	0.190
(gr/dscf)	(0.079)	(0.052)	(0.122)	(0.084)
gm/acm	0.154	0.102	0.238	0.165
(gr/acf)	(0.068)	(0.045)	(0.105)	(0.073)
kg/hr	1.22	0.77	2.04	1.36
(lb/hr)	(2.7)	(1.7)	(4.5)	(3.0)
kg/Mg	0.145	0.09	0.24	0.158
(lb/ton)	(0.29)	(0.18)	(0.48)	(0.32)
Total Catch				
gm/dscm				
(gr/dscf)				
gm/acm				
(gr/acf)		(Data not determined)		
kg/hr				
(lb/hr)				
kg/Mg				
(lb/ton)				

Table C-9 (continued). FACILITY D SUMMARY OF RESULTS - SCRUBBER OUTLET

Scrubber Particulate Removal Efficiency	--*	99.9	--*	99.9
Visible Emissions				
0 percent opacity, minutes observed	120	120	120	

---

*Inlet data not available with which to calculate scrubber efficiency

Table C-10. FACILITY E
SUMMARY OF RESULTS - SCRUBBER OUTLET*

Run Number	1	2	3	Average
Date	8/9/77	8/9/77	8/9/77	
Test Time-Minutes	80	64	64	69
AS Production Rate - Mg/hr	8.9	8.9	8.9	8.9
(TPH)	(9.8)	(9.8)	(9.8)	(9.8)
Dryer Vent Gas Data				
Flow Rate - acm/min	395	398	390	390
(acfm)	(13,974)	(14,079)	(13,807)	(13,953)
Flow Rate - dscm/min	345	377	342	355
(dscfm)	(12,197)	(13,338)	(12,116)	(12,550)
Temperature - °C	46	46	46	46
(°F)	(115)	(115)	(116)	(115)
Water Vapor - Vol. %	5.7	5.3	5.1	5.4
Particulate Emissions				
Probe and Filter Catch				
gm/dscm	0.0928	0.0538	0.0261	0.0577
(gr/dscf)	(0.0409)	(0.0237)	(0.0115)	(0.0254)
gm/acm	0.0814	0.0472	0.0232	0.0501
(gr/acf)	(0.0359)	(0.0208)	(0.0102)	(0.0223)
kg/hr	1.95	1.14	0.54	1.21
(lb/hr)	(4.28)	(2.51)	(1.19)	(2.66)
kg/Mg	0.22	0.13	0.06	0.14
(lb/ton)	(0.44)	(0.26)	(0.12)	(0.27)
Total Catch				
gm/dscm	(Data not determined)			
(gr/dscf)				
gm/acm				
(gr/acf)				
kg/hr				
(lb/hr)				
kg/Mg				
(lb/ton)				

Table C-10 (continued). FACILITY E
SUMMARY OF RESULTS -
SCRUBBER OUTLET

Scrubber Particulate Removal Efficiency	(Data not available with which to calculate)
Visible Emissions	(Data not determined)

*This test was done by the company test contractor.

Table C-11. FACILITY B SUMMARY OF RESULTS - CAPROLACTAM CONCENTRATIONS AND EMISSION RATES - SCRUBBER INLET

Run Number	1	2	3	Average
Date	10/3/78	10/4/78	10/4/78	
Test Time-Minutes	120	120	120	120
AS Capacity* - Mg/hr	26.5	26.5	26.5	26.5
(TPH)	(29.2)	(29.2)	(29.2)	(29.2)
Stack Effluent				
Flow rate - acm/min	1497	1491	1494	1494
(acfm)	(53,000)	(52,800)	(52,900)	(52,900)
Flow rate - dscm/min	1214	1194	1192	1200
(dscfm)	(43,000)	(42,300)	(42,200)	(42,500)
Temperature - °C	83	86	86	85
(°F)	(182)	(188)	(188)	(186)
Water vapor - Vol. %	3.5	3.7	4.0	3.7
Caprolactam Emissions				
Probe and Filter Catch				
ppm	1.90	4.67	<0.35	3.29
kg/hr	0.65	1.58	<0.118	1.118
(lb/hr)	(1.44)	(3.48)	(0.26)	(2.46)
kg/Mg	0.024	0.059	<0.004	0.042
(lb/ton)	(0.049)	(0.119)	(0.009)	(0.084)
Total In Vapor Phase				
ppm	49.9	60.3	63.3	57.8
kg/hr	17.18	20.45	21.45	19.68
(lb/hr)	(37.8)	(45.0)	(47.2)	(43.3)
kg/Mg	0.65	0.77	0.81	0.74
(lb/ton)	(1.30)	(1.54)	(1.62)	(1.49)

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*Plant B was operating close to capacity at the time of testing. Actual production rate is held company-confidential.

Table C-12. FACILITY B SUMMARY OF RESULTS - CAPROLACTAM CONCENTRATIONS AND EMISSION RATES - SCRUBBER OUTLET

Run Number	1	2	3	Average
Date	10/3/78	10/4/78	10/4/78	
Test Time-minutes	120	120	120	120
AS Capacity* - Mg/hr (TPH)	26.5 (29.2)	26.5 (29.2)	26.5 (29.2)	26.5 (29.2)
Stack Effluent				
Flow rate - acm/min (acfm)	1646 (58,300)	1629 (57,700)	1644 (58,200)	1641 (58,100)
Flow rate - dscm/min (dscfm)	1443 (51,100)	1418 (50,200)	1440 (51,000)	1435 (50,800)
Temperature - °C (°F)	40 (105)	43 (110)	40 (104)	41 (106)
Water vapor - Vol. %	6.1	6.1	6.4	6.2
Caprolactam Emissions				
Probe and Filter Catch				
ppm	0.201	0.26	0.28	0.201
kg/hr (lb/hr)	0.082 (0.181)	< 0.104 (0.28)	<0.113 (0.25)	0.082 (0.181)
kg/Mg (lb/ton)	0.003 (0.006)	< 0.004 (0.008)	< 0.0045 (0.009)	0.003 (0.006)
Total In Vapor Phase				
ppm	5.64	6.89	8.23	6.92
kg/hr (lb/hr)	2.31 (5.09)	2.77 (6.10)	3.36 (7.40)	2.81 (6.20)
kg/Mg (lb/ton)	0.087 (0.174)	0.104 (0.209)	0.126 (0.253)	0.106 (0.212)

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*Plant B was operating close to capacity at the time of testing. Actual production rate is held company-confidential.

Table C-13. AMMONIUM SULFATE PARTICLE SIZE DISTRIBUTION ANALYSIS

Facility: A
Date: 9/13/78
Sampling Method: Anderson Cascade Impactor

Plate No.	Effective Diameter, Microns	Net Wt. mg.	Weight Percent	Cumulative Wt. Percent
1	9.5	45.7	79.6	100
2	6.0	3.7	6.4	20.3
3	4.0	1.8	3.2	13.9
4	2.72	1.0	1.7	10.8
5	1.72	1.5	2.6	9.1
6	0.87	0.8	1.4	6.5
7	0.83	0.8	1.4	5.1
8	0.35	1.3	2.3	3.7
Back-up Filter		0.8	1.4	1.4
Total		57.4	100	

Table C-14. AMMONIUM SULFATE PARTICLE SIZE DISTRIBUTION ANALYSIS

Facility: B
Date: 10/4/78
Sampling Method: Brinks Cascade Impactor

Impactor Fraction	Range of Effective Diameter Microns	Net Wt. (mg)	Size Distribution by Weight Percent	Cumulative Percent
Cyclone	>8.04	289.2	99.3	100
Stage 1	2.74-8.04	2.0	0.7	0.7
Stage 2	1.62-2.74	<0.1	<0.1	<0.1
Stage 3	1.10-1.62	<0.1	<0.1	<0.1
Stage 4	0.58-1.10	<0.1	<0.1	<0.1
Stage 5	0.36-0.58	<0.1	<0.1	<0.1
Back-up Filter	<0.36	0.06	<0.1	<0.1
Total		291.4	100	

Table C-15. AMMONIUM SULFATE PARTICLE SIZE DISTRIBUTION ANALYSIS

Facility: C
Date: 12/6/78
Sampling Method: Anderson Cascade Impactor

Plate No.	Effective Diameter, Microns	Net Wt. mg.	Weight Percent	Cumulative Wt. Percent
1	≥11.8	450.4*	24.0	100.0
2	7.49	200.8	10.7	76.0
3	4.94	818.3	43.6	65.3
4	3.42	253.4	13.5	21.7
5	2.18	42.2	2.3	8.2
6	1.11	56.0	3.0	5.9
7	0.67	11.5	0.6	2.9
8	0.45	11.5	0.6	2.3
Back-up Filter	<0.45	31.3	1.7	1.7
Total		1875.4		

*Weight includes particulate collected in Plate No. 0 and in nozzle and head of sampler up stream of the collection plates.

Table C-16. AMMONIUM SULFATE PARTICLE SIZE DISTRIBUTION ANALYSIS

Facility: D
Date: 12/13/78
Sampling Method: Anderson Cascade Impactor

Plate No.	Effective Diameter, Microns	Net Wt. mg.	Weight Percent	Cumulative Wt. Percent
1	≥14.73	157.3	5.8	100.0
2	9.28	789.5	29.1	94.2
3	6.15	1271.6	46.8	65.1
4	4.26	413.8	15.2	18.3
5	2.11	71.2	2.6	3.1
6	1.40	13.2	0.5	0.5
7	0.85	0.5	0.0	0.0
8	0.58	0.0	0.0	0.0
Back-up Filter	<0.58	0.3	0.0	0.0
Total		2717.4		

Table C-17. PLANT A

a. Summary of visible emissions

	Test 1	Test 2	Test 3
Date	10/26/78	10/26/78	10/26/78
Type of Plant	Ammonium sulfate	Ammonium sulfate	Ammonium sulfate
Type of Discharge	Stack	Stack	Stack
Location of Discharge	Baghouse outlet	Baghouse outlet	Baghouse outlet
Height of Discharge Point (ft)	45	45	45
Distance from Observer to Discharge Point (ft)	25	25	25
Height of Observation Point (ft)	25	25	25
Direction of Observer from Discharge Point	NE	NE	NE
Description of Background	Solid gray building	Solid gray building	Solid gray building
Description of Sky	Partly cloudy	Partly cloudy	Partly cloudy
Wind Direction			
Wind Velocity (mph)	10-15	10-15	10-15
Color of Plume	a	a	a
Detached Plume	a	a	a
Duration of Observation (hrs)	1	1	1

[a] Plume was not visible

Table C-17. PLANT A (Concluded)

b. Summary of average opacity

Date	Set number	Time		Opacity	
		Start	End	Sum	Average
TEST 1					
10/26/78	1	8:50	8:56	0	0
	2	8:56	9:02	0	0
	3	9:02	9:08	0	0
	4	9:08	9:14	0	0
	5	9:14	9:20	0	0
	6	9:20	9:26	0	0
	7	9:26	9:30	0	0
	8	9:32	9:38	0	0
	9	9:38	9:44	0	0
	10	9:44	9:50	0	0
TEST 2					
10/26/78	1	10:44	10:50	0	0
	2	10:50	10:56	0	0
	3	10:56	11:02	0	0
	4	11:02	11:08	0	0
	5	11:08	11:14	0	0
	6	11:14	11:20	0	0
	7	11:20	11:26	0	0
	8	11:26	11:32	0	0
	9	11:32	11:38	0	0
	10	11:38	11:44	0	0
TEST 3					
10/26/78	1	12:22	12:28	0	0
	2	12:28	12:34	0	0
	3	12:34	12:40	0	0
	4	12:40	12:46	0	0
	5	12:46	12:52	0	0
	6	12:52	12:58	0	0
	7	12:58	1:04	0	0
	8	1:04	1:10	0	0
	9	1:10	1:16	0	0
	10	1:16	1:22	0	0

Table C-18. PLANT B

a. Summary of visible emissions

	Test 1	Test 2	Test 3
Date	10/3/78	10/4/78	10/4/78
Type of Plant	Ammonium Sulfate	Ammonium Sulfate	Ammonium Sulfate
Type of Discharge	Stack	Stack	Stack
Location of Discharge	Scrubber Outlet	Scrubber Outlet	Scrubber Outlet
Height of Discharge Point (ft)	55	55	55
Distance from Observer to Discharge Point (ft)	250	60	250
Height of Observation Point (ft)	0	55	0
Direction Observer from Discharge Point	105°E	SE	105°E
Description of Background	Green elevator shaft	Green elevator shaft	Green elevator shaft
Description of Sky	Overcast	Hazy	Hazy; partly cloudy
Wind Direction	125°SE	NE	45°NE
Wind Velocity (mph)	5	10	5-10
Color of Plume	White	White	White
Detached Plume	No	No	No
Duration of Observation (hrs)	3	2.3	2

Table C-18. PLANT B (Continued)

b. Summary of average opacity

Date	Set number	Time Start	 End	Opacity Sum	 Average
TEST 1					
10/3/78	1	3:15	3:21	60.00	10.00
	2	3:21	3:27	60.00	10.00
	3	3:27	3:33	60.00	10.00
	4	3:33	3:39	60.00	10.00
	5	3:39	3:45	60.00	10.00
	6	3:45	3:51	60.00	10.00
	7	3:51	3:57	60.00	10.00
	8	3:57	4:03	60.00	10.00
	9	4:03	4:09	60.00	10.00
	10	4:09	4:15	60.00	10.00
	11	4:15[a]	4:21	60.00	10.00
	12	4:21	4:27	60.00	10.00
	13	4:27[b]	4:33	60.00	10.00
	14	4:33	4:39	60.00	10.00
	15	4:39	4:45	60.00	10.00
	16	4:45	4:51	60.00	10.00
	17	4:51	4:57	60.00	10.00
	18	4:57	5:03	60.00	10.00
	19	5:03	5:09	60.00	10.00
	20	5:09	5:15	60.00	10.00
	21	5:15	5:21	60.00	10.00
	22	5:21	5:27	60.00	10.00
	23	5:27 6:00	5:31[c] 6:02	60.00	10.00
	24	6:02	6:08	60.00	10.00
	25	6:08	6:14	60.00	10.00
	26	6:14[d]	6:20	75.0	12.50
	27	6:20	6:26	90.0	15.0
	28	6:26	6:32	88.75	14.79
	29	6:32	6:38	90.0	15.0
	30	6:38	6:44	90.0	15.0

[a] Rain started at 4:15.
[b] Rain stopped at 4:40.
[c] System down. Wind velocity between 0-5 mph.
[d] Wind direction changed to NW.

Table C-18. PLANT B (Continued)

Date	Set number	Time		Opacity	
		Start	End	Sum	Average
TEST 2					
10/4/78	1	8:40	8:46	28.75	4.79
	2	8:46	8:52	30.00	5.00
	3	8:52	8:58	25.00	4.16
	4	8:58	9:04	20.00	3.33
	5	9:04	9:10	15.00	2.50
	6	9:10	9:16	23.75	3.95
	7	9:16	9:22	11.25	1.87
	8	9:22	9:28	17.50	2.91
	9	9:28	9:34	12.25	2.04
	10	9:34	9:40	1.25	0.20
	11	9:40	9:46	2.50	0.41
	12	9:46	9:52	0	0
	13	9:52	9:58	2.50	0.41
	14	9:58	6:04	2.50	0.41
	15	6:04	6:10	3.75	0.62
	16	6:10	6:16	0	0
	17	6:16	6:22	1.25	0.20
	18	6:22	6:28	0	0
	19	6:28	6:34	2.50	0.41
	20	6:34	6:40	3.75	0.62
	21	6:40	6:46	0	0
	22	6:46	6:52	3.75	0.62
	23	6:52	6:58	10.00	1.66
TEST 3					
10/4/78	1	2:15	2:21	57.50	9.58
	2	2:21	2:27	67.50	11.25
	3	2:27	2:33	60.00	10.00
	4	2:33	2:39	60.00	10.00
	5	2:39	2:45	60.00	10.00
	6	2:45	2:51	57.50	9.58
	7	3:26	3:30	52.50	8.75
	8	3:31	3:37	30.00	5.00
	9	3:37	3:43	30.00	5.00
	10	3:43	3:49	30.00	5.00

Table C-18. PLANT B (Concluded)

Date	Set number	Time		Opacity	
		Start	End	Sum	Average
TEST 3 (Continued)					
	11	3:49	3:55	30.00	5.00
	12	3:55	4:01	30.00	5.00
	13	4:01	4:07	30.00	5.00
	14	4:07	4:13	30.00	5.00
	15	4:13	4:19	30.00	5.00
	16	4:19	4:25	30.00	5.00
	17	4:25	4:31[e]	30.00	5.00
	18	4:31	4:37	30.00	5.00
	19	4:37	4:43	30.00	5.00
	20	4:43	4:49	30.00	5.00

[e] Wind direction changed to SE at 4:30.

Table C-19. PLANT C

a. Summary of visible emissions

	Test 1	Test 2
Date	12/6/78	12/6/78
Type of Plant	$(NH_4)_2SO_4$	$(NH_4)_2SO_4$
Type of Discharge		
Location of Discharge	Outlet	Outlet
Height of Discharge Point (ft)	50	50
Distance of Observer to Discharge Point (ft)	200	200
Height of Observation Point (ft)	0	0
Direction of Observer from Discharge Point	S	S
Description of Background	Sky[a]	Sky
Description of Sky	Clear	Clear
Wind Direction	NW	NW
Wind Velocity (mph)	10-20	10-25
Color of Plume	White	White
Detached Plume	No	No
Duration of Observation (hrs)	1	1

[a] Some interference from cooling tower in background.

Table C-19. PLANT C (Concluded)

b. Summary of average opacity

Date	Set number	Time		Opacity	
		Start	End	Sum	Average
TEST 1					
12/6/78	1	10:37	10:43	42.5	7.08
	2	10:43	10:49	50.0	8.33
	3	10:49	10:55	55.0	9.16
	4	10:55	11:01	67.5	11.25
	5	11:01	11:07	50.0	8.33
	6	11:07	11:13	55.0	9.16
	7	11:13	11:19	42.5	7.08
	8	11:19	11:25	47.5	7.91
	9	11:25	11:31	52.5	8.75
	10	11:31	11:37	60.0	10.00
TEST 2					
12/6/78	1	2:54	3:00	45.0	7.5
	2	3:00	3:06	75.0	12.5
	3	3:06	3:12	70.0	11.66
	4	3:12	3:18	70.0	11.66
	5	3:18	3:24	70.0	11.66
	6	3:24	3:30	77.5	12.9
	7	3:30	3:36	67.5	11.25
	8	3:36	3:42	75.0	12.5
	9	3:42	3:48	60.0	10.0
	10	3:48	3:54	67.5	11.25

Table C-20. PLANT D

a. Summary of visible emissions

	Test 1	Test 2	Test 3	Test 4
Date	12/12/78	12/12/78	12/13/78	12/13/78
Type of Plant	Ammonium sulfate	Ammonium sulfate	Ammonium sulfate	Ammonium sulfate
Type of Discharge				
Location of Discharge	Outlet	Outlet	Outlet	Outlet
Height of Discharge Point (ft)	20	20	20	20
Distance from Observer to Discharge Point (ft)	150	150	150	150
Height of Observation Point (ft)	0	0	0	0
Direction of Observer from Discharge Point	SE	SE	SE	SE
Description of Background	Sky	Sky	Sky	Sky
Description of Sky	Gray Clouds	Gray Clouds	Blue w/ Clouds	Clear Blue
Wind Direction	SE	S	S	S
Wind Velocity (mph)	0-20	10-20	0-10	0-15
Color of Plume	White	White	White	White
Detached Plume	No	No	No	No
Duration of Observation (hrs)	2	1.5	2.9	0.4

Table C-20. PLANT D (Continued)

b. Summary of average opacity

Date	Set number	Time		Opacity	
		Start	End	Sum	Average
TEST 1					
12/12/78	1	12:30	12:36	2.5	0.41
	2	12:36	12:42	17.5	2.91
	3	12:47	12:53	9.0	1.50
	4	12:59	1:05	12.5	2.08
	5	1:05	1:11	12.5	2.08
	6	1:11	1:17	10.0	1.66
	7	1:17	1:23	2.5	0.41
	8	1:23	1:29	7.5	1.25
	9	1:29	1:35	12.5	2.08
	10	1:35	1:41	5.0	0.83
	11	1:41	1:47	5.0	0.83
	12	1:47	1:53	15.0	2.50
	13	1:53	1:59	12.5	2.08
	14	1:59	2:05	20.0	3.33
	15	2:05	2:11	2.5	0.41
	16	2:11	2:17	7.5	1.25
	17	2:17	2:23	5.0	0.83
	18	2:23	2:29	7.5	1.25
	19	2:29	2:35	2.5	0.41
	20	2:35	2:41	10.0	1.66
TEST 2					
12/12/78	1	3:40	3:46	7.5	1.25
	2	3:46	3:52	5.0	0.83
	3	3:52	3:58	2.5	0.41
	4	3:58	4:04	7.5	1.25
	5	4:04	4:10	5.0	0.83
	6	4:10	4:16	5.0	0.83
	7	4:16	4:22	10.0	1.66
	8	4:22	4:28	7.5	1.25
	9	4:28	4:34	5.0	0.83
	10	4:34	4:40	5.0	0.83
	11	4:40	4:46	2.5	0.41
	12	4:46	4:52	2.5	0.41
	13	4:52	4:58	10.0	1.66
	14	4:58	5:04	2.5	0.41
	15	5:04	5:10	2.5	0.41

Table C-20. PLANT D (Concluded)

		Time		Opacity	
Date	Set number	Start	End	Sum	Average
TEST 3					
12/13/78	1	8:48	8:54	2.5	0.41
	2	8:54	9:00	0	0
	3	9:00	9:06	2.5	0.41
	4	9:06	9:12	2.5	0.41
	5	9:12	9:18	0	0
	6	9:18	9:24	0	0
	7	9:24	9:30	2.5	0.41
	8	9:30	9:36	0	0
	9	9:36	9:42	2.5	0.41
	10	9:42	9:48	0	0
	11	9:48	9:54	0	0
	12	9:54	10:00	2.5	0.41
	13	10:00	10:06	0	0
	14	10:06	10:12	2.5	0.41
	15	10:12	10:18	2.5	0.41
	16	10:18	10:24	0	0
	17	10:24	10:30	7.5	1.25
	18	10:30	10:36	0	0
	19	10:36	10:42	2.5	0.41
	20	10:42	10:48	0	0
	21	10:48	10:54	0	0
	22	10:54	11:00	2.5	0.41
	23	11:00	11:06	0	0
	24	11:06	11:12	0	0
	25	11:55	12:01	0	0
	26	12:01	12:07	2.5	0.41
	27	12:07	12:13	2.5	0.41
	28	12:13	12:19	0	0
	29	12:19	12:25	2.5	0.41
TEST 4					
12/13/78	1	2:37	2:43	10.0	1.66
	2	2:43	2:49	10.0	1.66
	3	2:49	2:55	5.0	0.83
	4	2:55	3:01	5.0	0.83

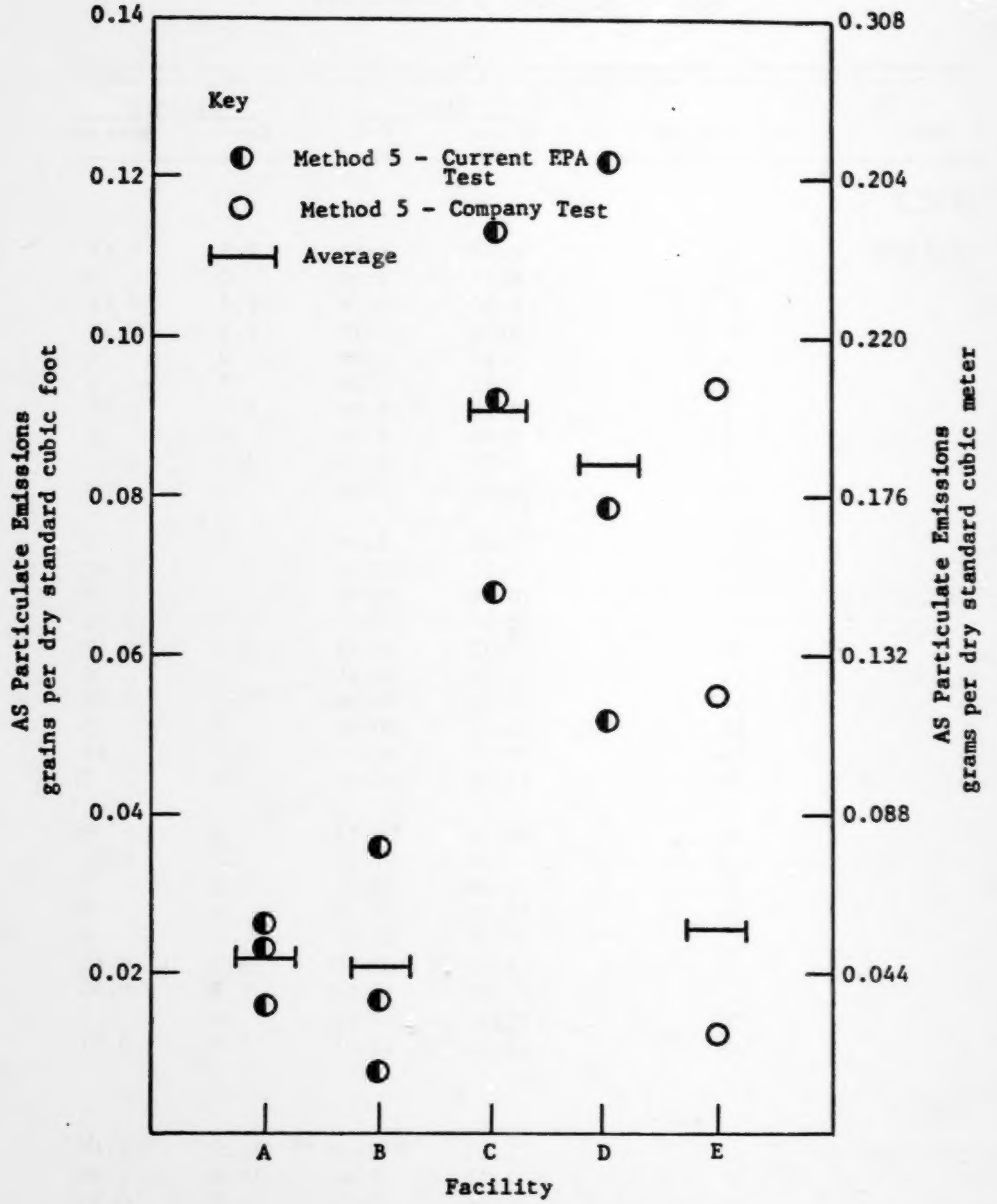

FIGURE C-1
CONTROLLED AS PARTICULATE EMISSIONS FROM EPA EMISSION TESTS—CALCULATED GRAIN LOADINGS

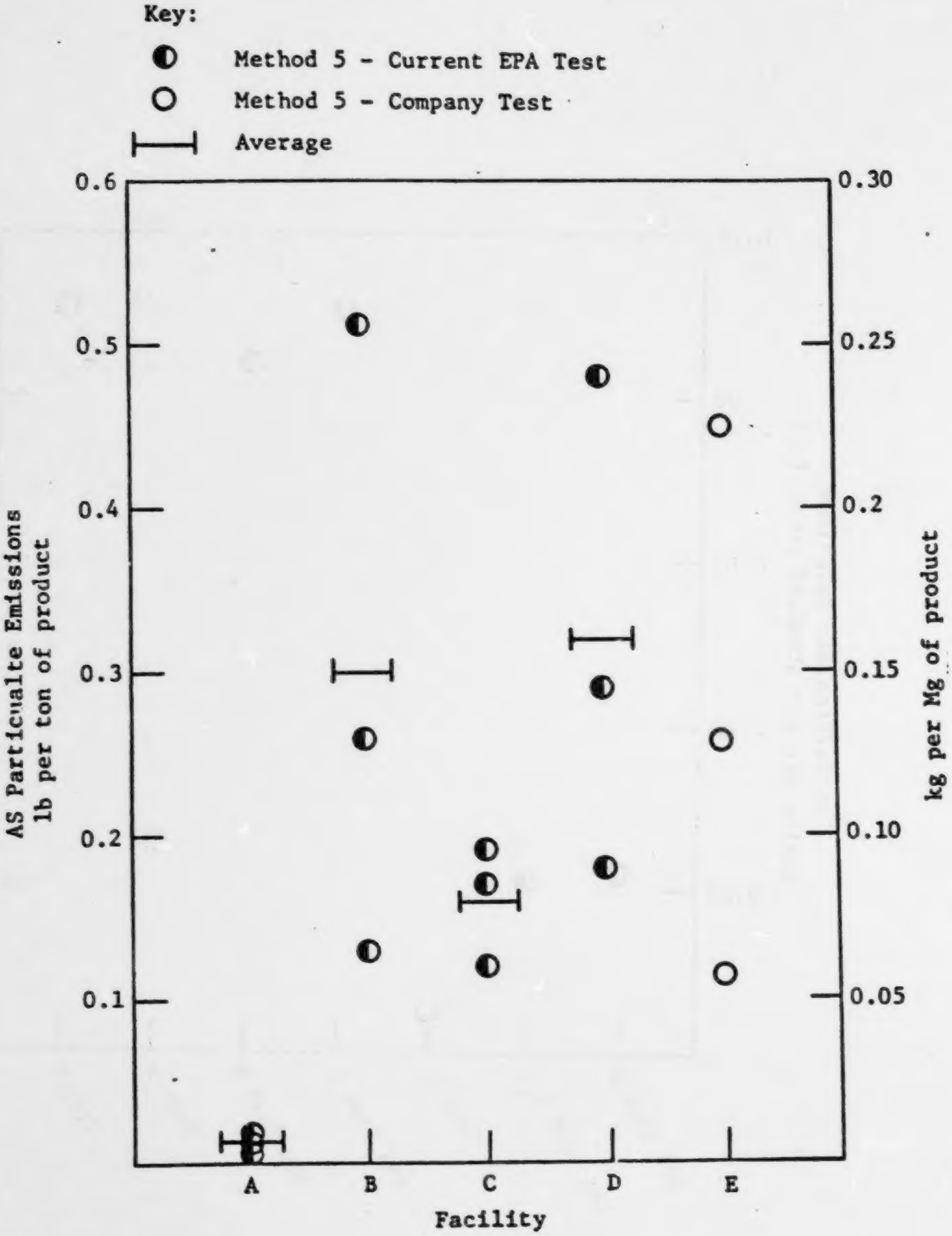

FIGURE C-2
CONTROLLED AS PARTICULATE EMISSIONS FROM EPA EMISSION TESTS—CALCULATED MASS EMISSION RATES

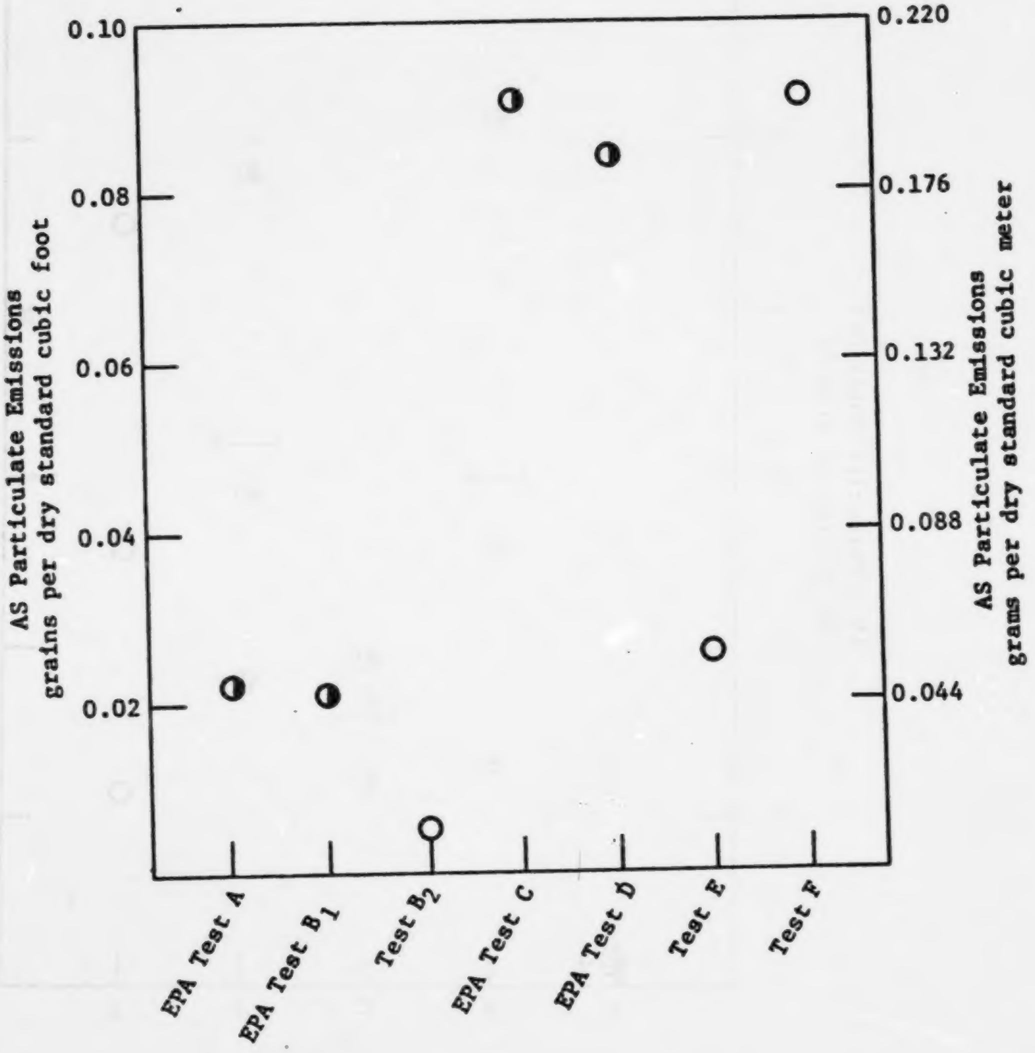

FIGURE C-3
AVERAGE CONTROLLED AS GRAIN LOADING TEST DATA—
EPA METHOD 5

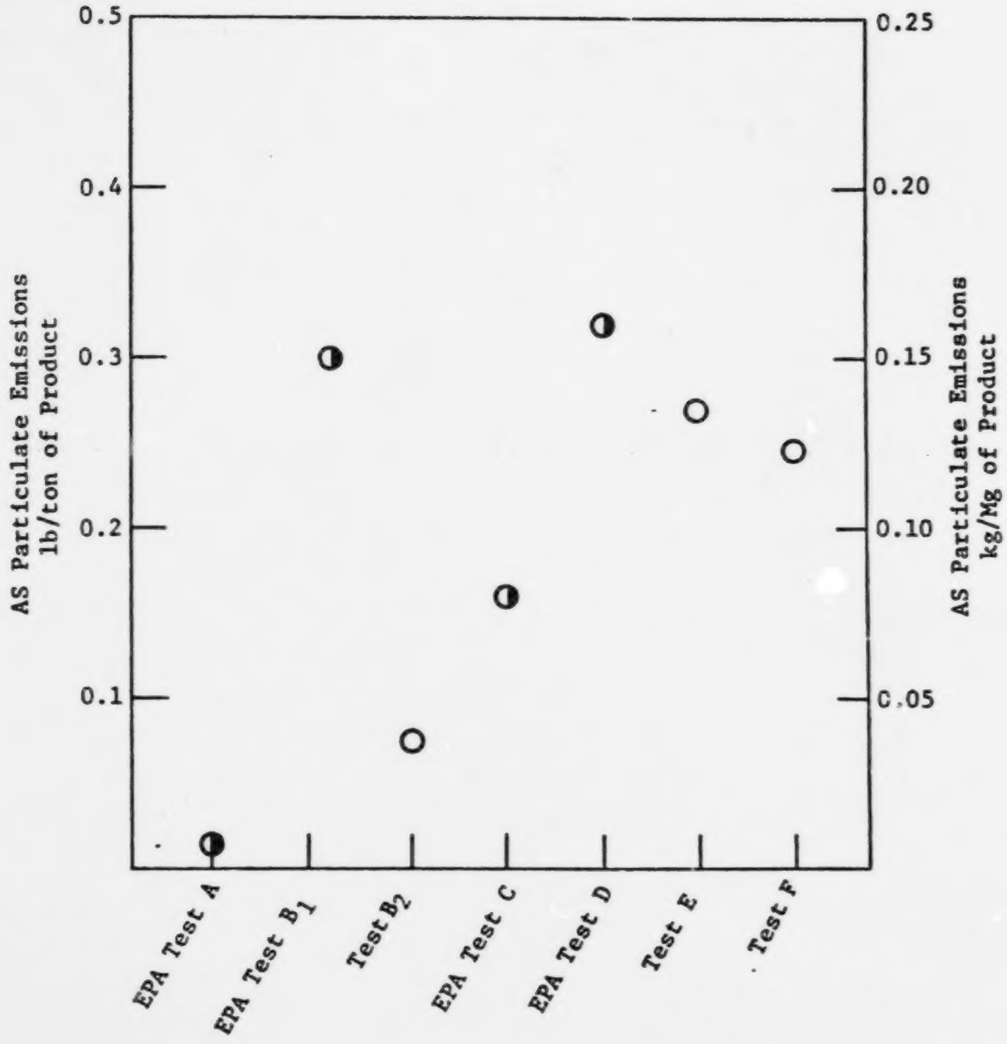

FIGURE C-4
AVERAGE CONTROLLED AS MASS EMISSION RATE DATA—
EPA METHOD 5

APPENDIX D

EMISSION MEASUREMENT AND CONTINUOUS MONITORING

APPENDIX D. EMISSION MEASUREMENT AND CONTINUOUS MONITORING

D.1 EMISSION MEASUREMENT METHODS

During the standard support study for ammonium sulfate manufacturing plants, EPA conducted particulate emission tests at four facilities, one controlled with a baghouse, and the other three with scrubbers. There were three test runs before and after each control system, and three test runs were repeated at the facility with the baghouse. The tests were run in accordance with EPA Mehtod 5 (40 CFR Part 60 - Appendix A). Method 5 provides detailed procedures and equipment criteria, and other considerations necessary to obtain accurate and representative particulate emission data. Visible Emission data were taken during the EPA tests in accordance with Method 9 (40 CFR Part 60 - Appendix A).

Of the four facilities tested, technical problems existed at three of them. The facility with the baghouse had a very high outlet emission rate due to some bags that were damaged. A decision was made to repeat the test after the baghouse was rebagged. Two of the facilities with scrubbers for controls had very high inlet loadings, causing clogging of the sampling nozzle; normal testing times were shortened to obtain samples.

D.2 MONITORING SYSTEMS

The opacity monitoring systems that are adequate for other stationary sources, such as steam generators, covered by performance specifications contained in Appendix B of 40 CFR 60 Federal Register, October 6, 1975, are also technically feasible for ammonium sulfate manufacturing plants except where condensed moisture is present in the exhaust stream. When wet scrubbers are used for emission reductions from ammonium sulfate plants, in-stack continuous monitoring of opacity is not applicable; EPA Method 9 would be required to determine opacity. Another parameter, such as pressure drop, would need to be monitored in order to provide a continuous indicator of emission control.

Equipment and installation cost for visible emission monitoring are estimated to be about $18,000 to $20,000 per site. Annual operating costs which include the recording and reducing the data, are estimated at about $8,000 to $9,000 per site. Some savings in operating costs may be achieved if multiple systems are used at a given facility.

D.3 PERFORMANCE TEST METHODS

Consistent with the data base upon which the new source standards have been established, the recommended performance test method for particulate matter is Method 5 (Appendix A, 40 CFR 60 - Federal Register), (December 23, 1971 as amended August 18, 1977). In order to perform Method 5, Methods 1 through 4 must be used.

Subpart A of 40 CFR 60 requires that affected facilities which are subject to standards of performance for new stationary sources must be constructed so the sampling ports adequate for the performance tests are provided. Platforms access, and utilities necessary to perform testing at those ports must be provided.

Sampling cost for performing a test consisting of three Method 5 runs is estimated to range from $5,000 to $9,000. If in-plant personnel are used to conduct tests, the costs will be somewhat less.

The recommended performance test method for visible emission is Method 9 (Appendix A, 40 CFR 60, Federal Register, November 12, 1974).

APPENDIX E

ENFORCEMENT ASPECTS

APPENDIX E. ENFORCEMENT ASPECTS

The recommended standard of performance will limit the emission of AS particulate matter from the AS dryer at new or modified AS production plants. This standard can be defined either as a concentration or a mass emission limitation coupled with a visible emission limitation. Compliance with either standard in a new plant can be achieved by installation of a dry collection system (baghouse) or a low-to-medium-energy wet scrubber such as a venturi scrubber. Each dryer is served by a separate control system. Aspects of enforcing the AS dryer standards of performance are discussed below.

E.1 PROCESS OPERATION

Factors affecting the level of uncontrolled AS particulate emissions from the AS dryer include AS feed rate, gas velocity, the residence time of the AS crystal, and its size distribution. Normally these factors do not vary under steady state operation. Feed rate of AS crystal to the dryer and crystal size distribution will be directly affected by upsets in upstream centrifuge and crystallizer operations, respectively. Monitoring of centrifuge drive current (directly affecting AS crystal feed rate to the dryer), and crystallizer liquor level, temperature and magma density and recirculation rate (affecting crystal size distribution) would ensure normal process operation during enforcement testing.

The process parameter that should be monitored to ensure that the AS dryer is operated normally during enforcement tests is the dryer's process weight rate. Due to the lack of product weigh scales in the industry, the process weight rate through the dryer is usually not possible to determine directly.

A material balance computation based on the chemical reactions used in the formation of ammonium sulfate is an acceptable method of determining production rate since the formation reactions used in all industrial sectors are quantitative and irreversible. If production rate is determined by material balance, the following equations shall be used.

(1) For synthetic and coke oven by-product ammonium sulfate plants, the ammonium sulfate production rate shall be determined using the following equation:

$$P = A \times B \times C \times 0.0808$$

where:

P = Ammonium sulfate production rate in megagrams per hour.

A = Sulfuric acid flow rate to the reactor/crystallizer in liters per minute averaged over the time period taken to conduct the run.

B = Acid density (a function of acid strength and temperature) in grams per cubic centimeter.

C = Percent acid strength in decimal form.

0.0808 = Physical constant for conversion of time, volume, and mass units.

(2) For caprolactam by-product ammonium sulfate plants the ammonium sulfate production rate shall be determined using the following equation:

$$P = [D \times E \times F \times (0.8612)] + [G \times H \times I \times (1.1620)]$$

where:

P = Production rate of caprolactam by-product ammonium sulfate in megagrams per hour.

D = Oximation ammonium sulfate process stream flow rate in liters per minute averaged over the time period taken to conduct the run.

E = Density of the process stream solution in grams per liter.

F = Percent ammonium sulfate in the process solution in decimal form.

G = Oleum flow rate to the rearrangement reaction in liters per minute averaged over the time period taken to conduct the run.

H = Density of oleum in grams per liter.

I = Equivalent sulfuric acid percent of the oleum in decimal form.

0.8612 = Physical constant for conversion of time and mass units.

1.1620 = Physical constant for conversion of time and mass units.

E.2 DETERMINATION OF COMPLIANCE WITH A CONCENTRATION STANDARD

Determination of compliance with a concentration (grain loading) standard involves measurement of particulate concentration in the exit gas from a control device. Devices used to control particulate emissions from the AS dryer normally exhaust their effluents to the atmosphere through a stack. The methods specified in 40 CFR 60 (methods 1, 2, 3, 4, and 5) provide specific guidelines for the measurement of particulate emissions from a stack. Use of these test methods will yield weight and volumetric flow data needed to calculate the concentration of particulate in the offgas.

Unlike existing facilities which sometimes require deviation from optimum sampling procedures due to physical limitations in the emission discharge configuration, new facilities can and should be designed to assure that optimum sampling conditions exist. For example, the optimum sampling location is a distance equal to 8 or more duct diameters downstream and 2 or more upstream from any constriction, expansion or other element that might disturb the flow pattern of the gas stream. Although the reference methods allow deviation from these optimum criteria, new facilities should be designed to ensure that the results from emission measurements are as accurate and precise as possible. Furthermore, utility services and sample access points can also be incorporated into the design of new sources to facilitate sampling.

Sampling problems encountered, where emissions are exhausted directly to the atmosphere, can be overcome by the use of stack extensions. These extensions may be either temporary or permanent and should be designed to conform as nearly as possible to optimum sampling criteria.

Monitoring of AS dryer process weight rate is also required to ensure that the dryer is operating at maximum rated capacity. This can be determined by indirect methods as indicated in Section E.1.

E.3 DETERMINATION OF COMPLIANCE WITH A MASS EMISSION STANDARD

Determination of compliance with an AS mass emission standard involves measurement of AS particulate concentration in the stack gas from a control device, the volumetric stack gas flow rate and the process weight rate from the AS dryer. EPA test Methods 1 through 5 (40 CFR 60) yield data with which to determine particulate concentration and volumetric flow rate. The AS process weight would in most cases be determined indirectly (as indicated in Section E.1). It has been found that indirect determination of process weight at AS plants is accurate to within ±5 percent. Therefore product weight scale are not being required by the Regulation.

Requirements for optimum sampling procedures would be similar to those described in Section E.2.

E.4 DETERMINATION OF COMPLIANCE WITH A VISIBLE EMISSION STANDARD

Due to the time and expense of performing quantitative emission measurements via EPA Methods 1 through 5, this test does not provide an economically feasible means of ensuring, on a day-to-day basis, that AS emissions are within the prescribed grain loading limit. A visible emission standard for AS particulate requires only an observer who is trained in reading of visible emissions. Determination of visible emissions can usually be performed with a minimal preparation and no prior notice to the owner. When promulgated with an AS particulate standard, a visible emission standard will assure that the emission control devices continue to be properly maintained and operated. All visible emission observations would be made in accordance with the procedures established in EPA Method 9 for stack emissions.

E.5 EMISSION MONITORING REQUIREMENTS

The recommended standards of performance do not require the installation of continuous monitoring system to monitor the opacity of the exit gas stream discharged into the atmosphere from the control device. Continuous opacity monitors range in cost from $5,000 to $7,000 with installation in the offgas stack ranging from one to two times equipment cost.[3] Continuous particulate monitors are still under development by manufacturers of stack monitoring equipment.

E.6 REFERENCES

1. Information provided by Chevron Chemical Corp., Richmond, Calif. in a conversation between Charles Moore and Marvin Drabkin of The MITRE Corporation, Metrek Division, on December 12, 1978.

2. Information provided by Dow Badische Corporation, Freeport, Texas, in a conversation between Karl Coffman and Marvin Drabkin of The MITRE Corporation, Metrek Division, on October 3, 1978.

3. Information provided by The MITRE Corporation, McLean, Va., in a conversation between Alberto Sabadell and Marvin Drabkin of The MITRE Corporation, Metrek Division, on March 20, 1979.